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THE LIMESTONE ORES OF MANHATTAN, NEVADA.

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INTRODUCTION.

Most of the ore deposits of the Manhattan district are gold-bearing veins of a simple type and present no unusual features, but other ores inclosed in a single thin bed of limestone offer interesting problems.

Manhattan is situated in the southern part of the northeasterly trending Toquima Range, about 35 miles north of Tonopah. The Toquima Range is one of the less prominent of the many narrow, isolated mountain ranges which are such notable features of the Great Basin topography. The range is bordered by desert valleys—Ralston Valley and Monitor Valley on the east and Big Smoky Valley on the west. On both sides, but particularly on the west, the boundary between rock in place and valley fill is irregular, in marked contrast to the sharp lines of demarcation on the eastern front of the Toyabe Range, which borders Big Smoky Valley on the west.

The district was first visited by the writer in the summer of 1915. At that time lode mining had suffered a collapse and little could be seen of the ore deposits. Work, therefore, was chiefly directed to a study of the complexities of the geologic structure

[1] Published by permission of the Director, U. S. Geological Survey.

and observations on the placers.[2] The district was revisited in 1919 and the geology of the principal deposits studied in some detail; another short visit made in June, 1920. The writer desires to acknowledge the courtesies extended to him by all the mining men of the district. The detailed geologic maps of the surface geology and underground workings of the White Caps mine, made by Messrs. O. McCraney and J. L. Dynan, were of especial value. The writer gratefully acknowledges the assistance in criticisms and helpful suggestions from his colleagues, particularly A. C. Spencer and W. T. Schaller.

The ore deposits of the present Manhattan district date from April, 1905, when "specimen ore" was discovered by John C. Humphrey on April Fool Hill. An old mine about 4 miles south of the present town of Manhattan had, however, been worked in the late sixties. The discoveries of rich surface ore with plentiful free gold were made within a few hundred feet of the road leading west from the old camp at Belmont. That such ore should be passed unnoticed for 40 years must be attributed to the inconspicuous croppings which characterize the later discovered deposits.

During 1906 the district was in a state of excitement and rich discoveries were constantly being reported. The winter of 1907–8 was marked by depression following the deflation of the boom, but the hard times, which led to temporary cessation of quartz mining, turned the attention of the miners to the placers of Manhattan Gulch. For several years lode mining was conducted spasmodically, and generally the placer output exceeded that of the lode mines. The best placer ground has, however, been exhausted since 1915, and since that time the lode output has been the more important. In 1917 the discovery of rich ore in the lower levels of the White Caps mine led to another boom, which, though short lived, led to a considerable amount of exploratory work. At the present time a small amount of

[2] Ferguson, H. G., "Placer Deposits of the Manhattan District, Nevada," U. S. Geol. Survey Bull. 640, pp. 163–193, 1917.

exploration work is being carried on, but the production is principally from the shallow surface workings of lessees.

GENERAL GEOLOGY.

The rocks of the southern portion of the Toquima Range include Paleozoic sediments, intrusive granodiorite masses of Cre-

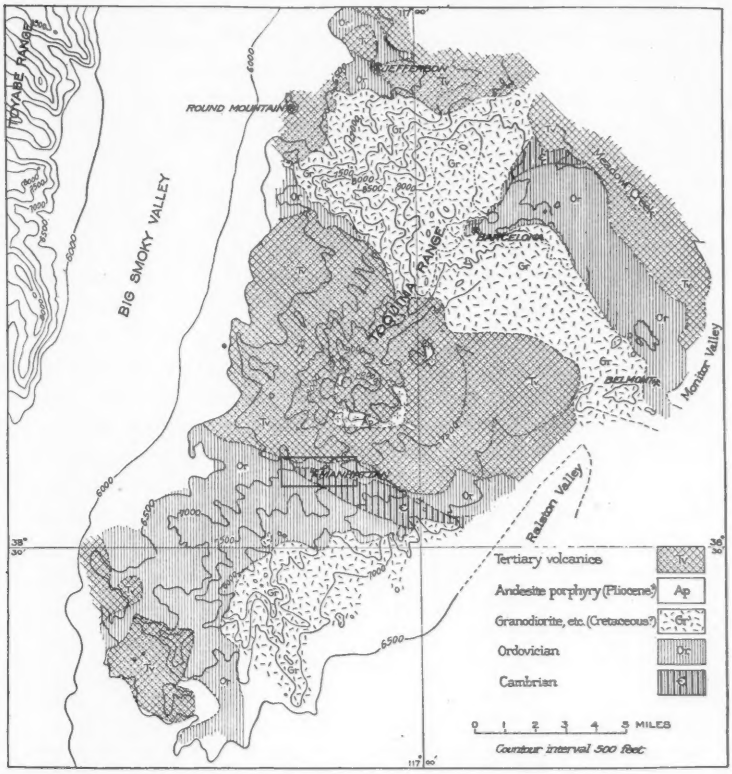


FIG. 1. Geologic map of the southern part of the Toquima Range.

taceous or Eocene age and Tertiary lavas and sediments and intrusives. In the productive portion of the Manhattan district

(fig. 2) the older sediments are of Cambrian or Ordovician age, intensely folded, cut by many faults and everywhere more or less metamorphosed.

Paleozoic Sediments.—The Cambrian sediments, in which are the productive ore bodies, consist principally of micaceous schists. Lenticular beds of white quartzite and dark fine-grained sandstone are common. There are also several limestone beds, of which three in the lower part of the formation, and two near its top are sufficiently well defined to be traced on the surface. Other smaller beds are less persistent. Since many of the deposits occur as replacements in limestone, these beds have been well exposed by prospecting, and consequently the structure of this part of the district could be worked out in detail.

The three lower beds are but slightly altered and consist of blue-gray or white, fine-grained crystalline limestone. The lowest, locally known as the Pine Nut limestone, is about 10 feet thick and is the only one which shows any development of silicate minerals, and that only in scattered nodules. The next, known as the Morning Glory limestone, is 15 to 20 feet thick and consists of pure crystalline limestone. The third bed, the White Caps limestone, is 30 to 35 feet thick and forms the wall rock of some of the most important deposits of the region. Except where altered by mineralizing solutions, it is a pure crystalline limestone, light blue in color and essentially free from silicates. The two limestones in the upper part of the Cambrian terrane, on the other hand, show a considerable development of silicates and range from white crystalline limestones to rocks consisting essentially of diopside. The total thickness of Cambrian sediments exposed in the district probably exceeds 3,000 feet.

Above the Cambrian and tentatively assigned to the Ordovician is a fine-grained dark schist, about 400 feet thick. Above the dark schists is a series composed principally of a dark-gray thin-bedded limestone, associated with which are varying amounts of black jasper. This series is probably less than 400 feet thick.

The first fossiliferous horizon is found above this dark lime-

stone. There are lenticular beds of dark quartzite, overlain by a few feet of slates carrying well-preserved graptolites, indicating a horizon equivalent to a part of the upper Pogonip formation of the Eureka district[3] and to the Palmetto formation of the Silver Peak quadrangle.[4] Above this is a dark jaspery limestone, a few feet in thickness, identical in character with that below the quartzite. Above this is a considerable thickness of chloritic schist similar to that found directly above the Cambrian, but here diversified by occasional beds of impure brown limestone and dark blocky slate.

An isolated outcrop of Carboniferous (Pennsylvanian) sandstone was found about a mile northwest of Manhattan. The relations to the other sediments are undetermined.

Granitic Rocks.—Large masses of granitic rocks occupy a considerable area in the Toquima range. The rock is in general coarsely porhpyritic, with numerous orthoclase phenocrysts, up to a couple of inches in length. Microscopic examination shows that it ranges in composition from a soda-granite to a granodiorite, more commonly the latter. There are also many dikes of very fine-grained aplite. These consist essentially of quartz and orthoclase with varying amounts of muscovite and a small amount of pyrite, apparently original. In places quartzose segregations in the aplites form a connecting link with the quartz veins. Spurr[5] describes an occurrence in the nearby Belmont district, in which an aplite dike grades into a metalliferous quartz vein.

The nearest large exposure of granitic rock lies about 2 miles to the south of the productive mines. But it is probable that there is a nearer granite mass to the north, beneath the Tertiary lavas, since pebbles of granite are common in the lower rhyolite

[3] Walcott, C. D., Mon. U. S. Geol. Survey, vol. 8, p. 284, 1884.
Hague, A., Mon. U. S. Geol. Survey, vol. 20, p. 58, 1892.
Spurr, J. E., Bull. U. S. Geol. Survey No. 208, p. 91, 1903.

[4] Turner, H. W., "A Sketch of the Historical Geology of Esmeralda County, Nev.," *Amer. Geologist*, vol. 29, p. 265, 1902.

[5] Spurr, J. E., "Quartz Muscovite Rock from Belmont, Nevada," *Am. Jour. Sci.*, 4th Ser., vol. 10, p. 351, 1900.

breccias, and the Ordovician limestones on Salisbury Hill just south of the lava-covered area and show intense contact metamorphism. There is, however, a small dike of coarse muscovite granite grading into aplite, about 1,500 feet northeast of the White Caps mine, and two small masses of a much altered aplitic rock have been cut on the 800-foot level of the White Caps.

The age of the granodiorite is probably late Cretaceous or early Tertiary, though no conclusive data can be obtained in this range. Although the granitic intrusion probably closely followed the mountain-building movements which produced the intense folding, there is no evidence of any direct association. The major folds had been developed before the rise of the intrusive to the level of the present surface, for the granodiorite cuts the folded rocks at all angles and shows no sign of any gneissic structure or even of important shearing. There is no evidence of doming of the sediments by the intrusive.

The rim of intense metamorphism surrounding the granite is narrow. The limestones close to the contact are epidotized and abundant biotite is developed in the schists. The more distant effects are shown in the development of silicate minerals, particularly diopside, in some of the limestones and the presence of small knots of silicates in the Ordovician schists.

Tertiary Rocks.—The Tertiary rocks lie to the north of the productive part of the district and consist predominantly of rhyolite. The earliest is a breccia composed of angular fragments of the older rocks without volcanic material. Rhyolite braccias containing fragments of the underlying sediments form a large part of the effusive rocks. The lower breccias are cut by irregular intrusions of a fine-grained rhyolite. Near the top of the Tertiary series is a considerable thickness of shale, fine-grained sandstone, water-laid tuff, and conglomerate. The finer grained phases of this resemble very closely the Siebert tuffs of the Tonopah district considered to be of late Miocene age. Above this comes another series of rhyolite breccias. Following this there was intruded a considerable mass of rather coarse andesite porphyry. The principal body of this rock lies about 2 miles to

the northeast of the White Caps mine and numerous smaller masses and dikes occur throughout the region. The principal intrusive mass appears to be laccolithic in nature and has tilted and wedged apart the tuffs and breccias which it intrudes.

Structure.—The Paleozoic rocks are compressed into close folds in part overturned toward the north. The axes of the major folds trend a few degrees to west of north, at right angles to the present trend of the Toquima range. The principal anticline is cut off obliquely on its northern side by an overthrust fault which brings the Cambrian above the Ordovician schists and limestone. The overthrust dips to the south and southwest at from 36° to 70°, and was undoubtedly formed at the time of folding of the sediments through the irregularities of its plane may be in part due to later faulting and tilting. A normal fault along the southern border of the Cambrian schists may also date from this period, since it is cut by later faults trending in an opposite direction.

As may be seen from the detailed geologic maps (Figs. 2 and 3), the productive part of the region is cut by a large number of small normal faults. These could be mapped with certainty only in the portion of the territory traversed by the Cambrian limestone. In one instance, a small dike of alaskite appears to occupy a fault plane. Two of the faults were traced to the northward across Salisbury Mountain. On the northern slope of the mountain the contact between the Ordovician and the Tertiary breccia follows the strike of one of these faults, so it is to be presumed that faulting was of Tertiary age. The field relations, however, do not preclude the possibility that the breccia was deposited against a pre-Tertiary fault scarp. The faults are roughly parallel, for the most part varying in strike from a few degrees east of north to about east-northeast, and there is a tendency for those of more northerly strike to be cut off by those trending to the eastward. This intense normal faulting is confined to the productive portion of the district. Numerous small faults are, however, observable in the vicinity of the prospects in the lavas on Bald Mountain, 3 miles to the north. There are also normal

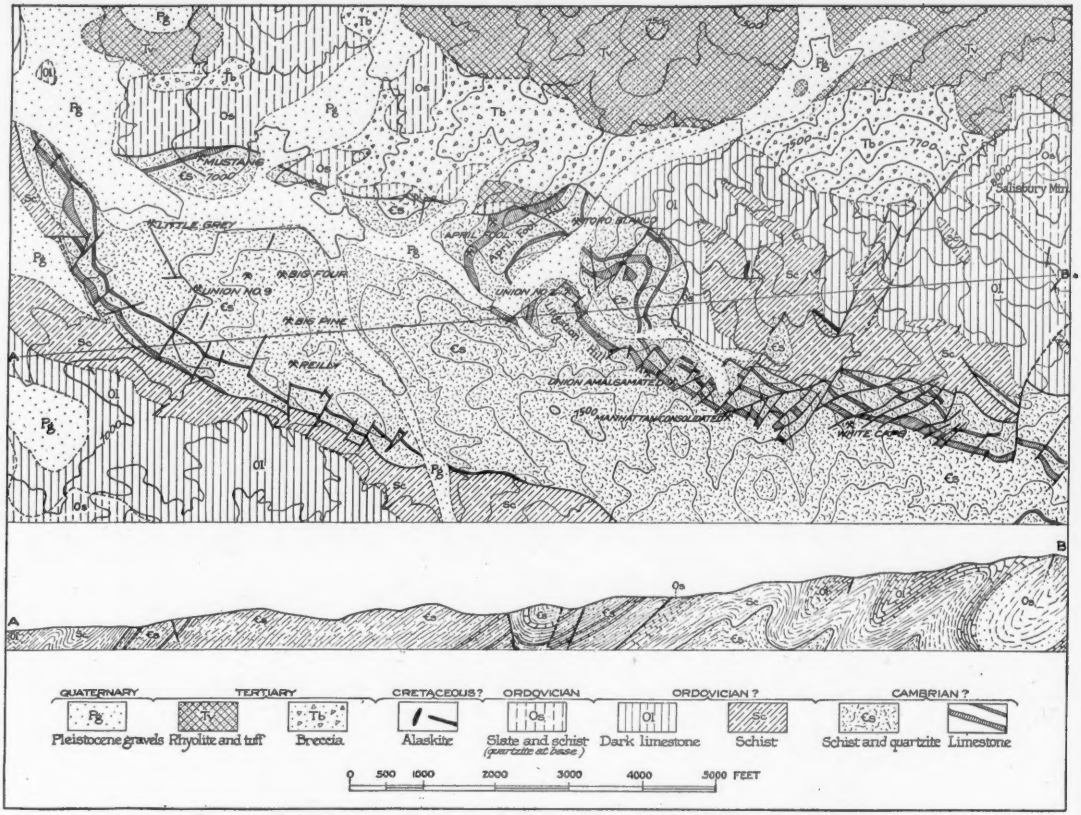


FIG. 2. Geologic map of the productive portion of the Manhattan district.

faults of considerable magnitude which in places cut the lavas but do not appear to extend to the sediments of the Manhattan district. These appear to be younger than the intrusion of the andesite prophyry and probably owe their origin to the readjustments following this intrusion. There is likewise evidence of a period of faulting in the lavas prior to the andesite intrusion.

Erosion.—The lava-covered region was eroded until an extremely mature topography, approaching the peneplain stage, was reached. The topography was fairly general over this portion of the Great Basin region, for Ball[6] mentions the existence of similar old topographic forms on other ranges to the south, and Meinzer[7] has found a similar mature topography on the Toyabe Range. Ball considers this mature land surface to be late Pliocene in age, as it is later than the "later rhyolite" of early Pliocene age and older than the later tuffs and older alluvium which mark the transition from Pliocene to Pleistocene. Hence the major portion at least of the mountain-building movements must have been confined to the early Pleistocene, for at the period marked by the Pleistocene lakes a topography approaching the present had been attained.

The eastern face of the Toyabe Range, a few miles west of Manhattan, presents a well-marked fault scarp. Faulting has continued until recent times, for Meinzer[8] reports that fault scarps cut the alluvial fans at the canyon mouths.

Small patches of Pleistocene gravel occur here and there along the borders of Manhattan Gulch, and the deep gravels of the gulch contain fragments of bones of Pleistocene mammals.

It is evident that a topography which at least in its main outlines resembled the present, has been developed in Pleistocene time. During a period of milder climate than the present, pre-

[6] Ball, S. H., "A Geologic Reconnaissance in Southwestern Nevada and Eastern California," U. S. Geol. Survey Bull. 308, pp. 16–17, 99, 119, 161, 202, 1907.

[7] Meinzer, O. E., "Ground Water in Big Smoky, Clayton and Alkali Valleys, Nev.," U. S. Geol. Survey Water Supply Paper 423, p. 21, 1917.

[8] Meinzer, O. E., *op. cit.*, p. 22.

FIG. 2. Geologic map of the productive portion of the Manhattan district.

sumably contemporaneous with the Pleistocene lakes Bonneville and Lahontan, two lakes existed in Big Smoky Valley.[9]

ORE DEPOSITS.

VEINS.

The ores of the Manhattan district occur in veins and as replacement deposits in limestone. Two types of vein deposits are present, an unimportant older group, connected in origin with the intrusive grandiorite masses of the region, and a younger group which is regarded as having been formed during the period of Tertiary volcanism, although the productive deposits are inclosed in the Cambrian sediments. The replacement deposits in the Cambrian limestones are allied mineralogically with the Tertiary veins, and, though the evidence is inconclusive, they are regarded as of contemporaneous origin.

Older Veins.—Veins of the older groups have not been profitably worked in the Manhattan District, though elsewhere in the region deposits genetically connected with the granodiorite and showing mineral associations characteristic of a more deep-seated origin than the Tertiary veins have supported workable silver mines, as at Belmont, 15 miles to the northwest of Manhattan, and Barcelona, near the crest of the range between Belmont and Round Mountain. In the Manhattan District the veins representing this epoch of mineralization are characteristically narrow and of no great continuity. They are composed of white glassy quartz with minor amounts of calcite and here and there contain patches of coarsely crystalline sulphides, including pyrite, galena, tetrahedrite, and chalcopyrite. The tenor in precious metals is low and the silver content is commonly greater than the gold. Tourmaline occurs as a minor gangue mineral in a few veins of this type. In one vein a little feldspar (orthoclase or albite) is present, thus forming a connecting link with the quartzose segregations of the aplite dikes.

Tertiary Veins.—The volcanic rocks, including the andesite

[9] Meinzer, O. E., *op. cit.*, p. 30.

porphyry, which is post-Siebert (Miocene) in age, contain small veins, apparently not continuous over long distances, which usually follow joint cracks or minor faults in the lava. The ore of these consists of minute veins of comby iron-stained quartz, with minor amounts of tabular calcite, which is largely replaced by quartz, and rarely fluorite and adularia. Pyrite has been present but is now completely oxidized to limonite. Here and there minute specks of free gold can be seen on the surface of the grains of oxidized pyrite.

The veins of Tertiary age in the Cambrian schists have been the largest producers of the Manhattan district. These are confined to the vicinity of Gold Hill, just west of the town. The ores are of relatively simple type. At the Reilly Fraction, Big Pine and Big Four mines the schists are traversed by innumerable little veinlets, for the most part following the bedding and jointing. These stringers contain free gold in a gangue consisting chiefly of comby quartz, but in places containing quartz pseudomorphic after tabular calcite together with clusters of adularia crystals. The enclosing schists are pyritized in places, but this pyrite is said to be practically barren. The zone of workable ore is fairly well defined and is about 50 feet wide and 800 feet long. In the Big Four mine the ore is stoped to a depth of 300 feet, about 100 feet above permanent water level, but most of the production from the three mines has come from less than 100 feet depth.

The group of mines west of the summit of Gold Hill, including the Stray Dog, Jumping Jack, Union No. 9, and Little Gray, shows the same type of mineralization, but here the veins are better defined and follow faults. There has been later movement along many of the veins and also along planes intersecting the veins at small angles. Where this has occurred, gold, probably of secondary derivation, is found in association with crushed vein material and gougy manganese oxide.

The mineralogical character of the schist ores, particularly the presence of abundant adularia and lamellar calcite replaced by quartz, indicates that they belong to the class of veins formed

under near-surface conditions. The similarity of vein filling to that of the unproductive veins in the lavas suggests very strongly that both sets are of contemporary origin.

DEPOSITS IN LIMESTONE.

The ore deposits in the limestone beds of the Cambrian show most complex mineralization and a wide variety of minerals. Productive mineralization is almost entirely confined to a single limestone bed, the upper of the three lower limestones, locally known as the White Caps limestone. This bed has been traced from a point about a mile east of the White Caps mine through Litigation Hill to the summit of April Fool Hill, where it is cut off against the overthrust fault. Throughout its course it is broken by closely spaced normal faults, mostly of small throw. This faulting appears to be most intense and complicated in the region between the White Caps and Manhattan Consolidated shafts. A detailed study of this region was made by Messrs. McCraney and Dynan of the White Caps Company in connection with the White Caps-Morning Glory litigation in 1917, and through the courtesy of the officials of the White Caps Company, their map, with slight changes by the writer, is here reproduced (Fig. 3). The region west of the Consolidated shaft was mapped by the writer on a much smaller scale, which admits of showing only the more important of the faults.

Occasional reverse faults strike in the same general direction as the limestone and are shown by the repitition of the limestone on the 300-foot level of the Manhattan Consolidated, and on the 600-foot level of the Union Amalgamated.

The different mines in the limestone, although near neighbors, show such a wide diversity in their mineralization that a short description of each will be given before the theoretical side of the ore deposition is discussed.

White Caps Mine.—The White Caps mine appears to mark the eastern limit of profitable mineralization of the limestone. The Zanzibar, White Caps Extension and Red Caps prospects

have explored the limestone bed to the east, but so far without success.

The White Caps mine is developed by seven levels, the lowest of which is 800 feet below the collar of the shaft. The limestone is here cut by three major faults which strike northeasterly and dip southeast. These are known as the East Fault, White Caps

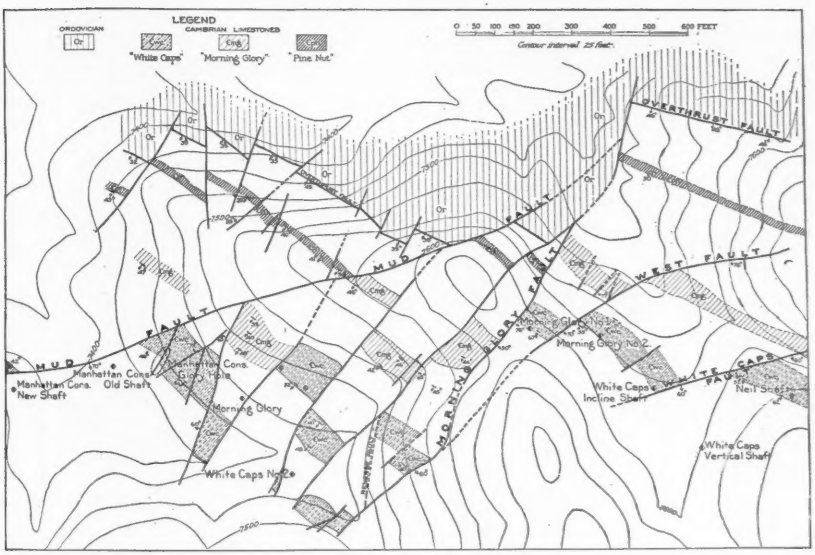


FIG. 3. Geologic map of area between the White Caps and Manhattan Consolidated mines, by O. McCraney and J. L. Dynan, with minor modifications by H. G. Ferguson.

Fault and West Fault. There are also a number of small northerly faults whose horizontal displacement in most cases does not exceed 5 or 10 feet. There has been more recent movement on the three main faults than on the minor faults, since they cut the earlier series and contain rounded fragments of ore. The earlier faults preceded the ore deposition and apparently to a large extent controlled it. They are cemented by ore and almost lose their identity in the ore bodies.

The ore bodies occur as large replacements in the limestone. It is rare that mineralization extends completely across the bed but usually follows one wall, more commonly the footwall. The areas in which the small faults are most numerous appear to be best mineralized. It is not uncommon for the ore and associated mineralized limestone to have a horizontal section of as much as 100 by 30 feet. Two main zones of mineralization have been developed, the east ore body which has yielded ore from the

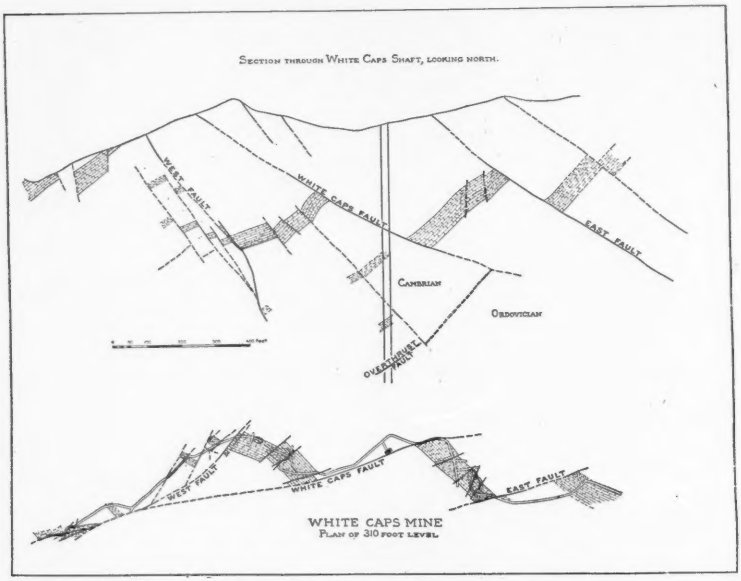


Fig. 4. Section through White Caps shaft, looking north; and plan of 310-foot level. (Mineralized areas shaded.)

surface to the 800-foot level, and the zone containing the West and Shaft ore bodies, which has been productive from near the 100-foot level to the 550-foot level. The eastern ore body has a steep easterly pitch, which brings it in contact with the east fault between the 550 and 800-foot levels. The western body is in

contact with the White Caps fault between the 450 and 550-foot levels.

The gangue minerals of the White Caps mine are calcite, quartz, and less commonly dolomite, fluorite, and leverrierite. The metallic minerals include arsenopyrite, pyrite, stibnite, realgar and orpiment. Cinnabar is reported to have been present in the ore found above the 200-foot level.[11] The arsenopyrite, realgar, and orpiment are auriferous, but visible gold is completely lacking even in the oxidized ore. Oxidized minerals, present only in minor amount and confined to the two upper levels, include limonite melanterite and oxidation products of stibnite such as valentinite and stibioconite.

The following analysis of ore from the 300-foot level is quoted from Dynan's paper:[12]

SiO_2.	Al_2O_3.	CaO.	Fe	S.	Sb.	As.	Mgo.	H_2O.	CO_2.	Total.
55.8	1.8	7.2	8.9	8.2	0.7	1.5	3.2	0.8	9.2	97.3

Dynan has calculated from this the following mineral composition:

Pyrite	13.8%
Arsenopyrite	3.3
Stibnite	1.0
Calcite	19.6
Quartz	52.0
(Ca, Fe, Al) Silicates	7.4
	97.1

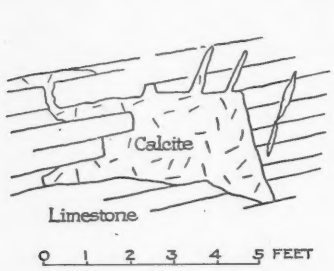
Ore from the lower levels of the eastern ore body shows a much higher percentage of arsenic.

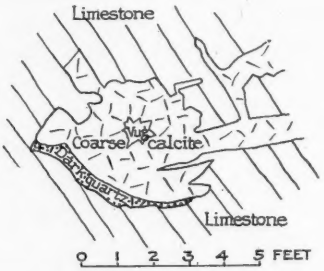
The earliest of the minerals associated with the ore is white calcite. Huge rhombs are often observed in large irregular shrinkage cavities. The mineral is coarsely crystalline, and cleavage faces 8 inches across are frequently seen. The alteration of limestone to coarse calcite commonly follows the bedding and joint planes of the limestone. These replacements vary in

[11] Dynan, J. L., "The White Caps Mine, Manhattan, Nev.," *Mining and Scientific Press*, vol. 13, p. 885, Dec. 16. 1916.

[12] Dynan, J. L., *lac. cit.*, p. 884.

size from small lenses an inch or two across to large masses extending nearly across the limestone bed. The calcite is usually glaring white in color, except where the presence of finely divided realgar imparts a pinkish tinge. In a few places, however, small pieces have been obtained approximating Iceland spar in clearness and transparency. As far as known, the calcite itself is everywhere barren and is most plentiful near the outer edges of the ore bodies. In parts of the mine some coarse white





FIGS. 5 and 6. Calcite replacing limestone, 400 foot level, White Caps mine.

calcite occurs unaccompanied by ore, and is also found here and there throughout the district, even in the dark Ordovician limestone, though it is best developed in the ore-bearing limestone. The calcite is persistent in depth. The best ore of the mine consists of a dark, fine-grained quartz, in places so dense as to have the appearance of black jasper. This occurs as a replacement of the limestone and, to a less extent, of the coarse calcite. The quartz is closely confined to the ore bodies and does not show the wide distribution characteristic of the barren calcite. The replacement of limestone by quartz has involved a considerable loss of volume, indicated by numerous drusy cavities, usually elongate with the bedding of the limestone. In these minerals of later age —dolomite, stibnite, realgar, and orpiment, have been deposited. In places this reduction of volume, possibly assisted by the abstraction of the arsenopyrite by later solutions, has been sufficient to permit collapse and local brecciation of the quartz, following later movement along the major faults.

The hand lens discloses occasional minute specks of pyrite in the quartz. Under the high power of the microscope, however, the dark color is seen to be due to the presence of carbonaceous matter and minute crystals of a gray metallic mineral. These range from the lower limit of visibility to a maximum of 0.05 mm., but most of them are less than 0.22 mm. in diameter. Many of these little crystals are so twinned as to resemble minute jackstones. Qualitative tests indicate that the metallic mineral is arsenopyrite. Evidently it is highly auriferous for assays exceeding $200 per ton have been obtained from this type of ore. No gold can be seen under the microscope and none is obtainable by amalgamation. Palmer,[13] however, found that this dark ore, concentrated by panning and treated with nitric acid, yielded minute specks of free gold.

A little muscovite was observed in some of the thin sections of the dark quartz. It is not certain whether this is contemporaneous with the inclosing quartz or is residual from the limestone, though no muscovite was found in the few sections of the limestone examined.

The replacement ore deposits are later than the first period of faulting, since both quartz and calcite, but especially the quartz, are found recementing the shattered zones where the minor faults enter the limestone. On the other hand, they are clearly older than the last movement on the larger faults for these contain rounded fragments of the quartz.

Dolomite, stibnite, realgar and orpiment, with minor leverrierite and rarely fluorite, are clearly younger than the quartz and calcite since they were deposited in open spaces of the cellular and brecciated quartz. The realgar and orpiment, at least, are subsequent to the second period of faulting since small crystals occur in the fault gouge.

Stibnite is found throughout the deposit, but is more prominent in the western part of the mine. Small crystals are frequently found in the vugs of the dark quartz. Its most usual occurrence

[13] Palmer, W. S., "Occurrence of Gold in Sulphide Ore," *Eng. Min. Jour.*, vol. 107, pp. 923-924, May 24, 1919.

is in roughly radiate crystalline masses, in places several inches in diameter, which replace the limestone or coarse calcite, or more rarely the dark quartz. In places small "sunbursts" of stibnite crystals occur along cleavage planes of the coarse calcite and small needles were found in the fault gouge of the later faults. In all these positions, particularly in the eastern ore body, stibnite may be closely intergrown with realgar. A rare occurrence of stibnite is in the form of delicate hair-like crystals found in cavities in the calcite and rarely in the quartz. Orpiment is found in this same habit and association, but not realgar. Although the stibnite is practically barren of gold it is confined to the ore bodies. Only rarely do small clusters of stibnite crystals occur ouside of the mineralized areas.

Realgar occurs in large amounts in the eastern ore body but only sparingly in the western part of the mine. In the stope above the 665-foot level and on the 400-foot level realgar was present in such large masses that it was smelted as an ore of arsenic. The mode of occurrence is very similar to that of the stibnite. It is found as a replacement of the coarse calcite, in crystalline masses whose boundaries follow the cleavage planes of the calcite, in narrow streaks following the cleavages; it is also common as a filling of the numerous cavities in the dark quartz. A stope above the 665-foot level shows realgar and dark quartz in irregular bands up to several inches across. In places blocks of practically pure realgar a couple of feet in diameter have been obtained. The realgar is gold-bearing, though, as far as the writer is aware, does not yield such high assays as are sometimes obtained from the dark quartz. Smelter shipments of 30 per cent. arsenic, carried $20 to the ton in gold.

In the vicinity of the ore, but outside the ore bodies, realgar is more widely distributed than the other minerals. It is the only ore mineral found outside the limestone and occurs in the foot and hanging wall slates in small veinlets and impregnations for distances of a few feet from the limestone. Realgar, in small scattered crystals, is found in places in the fault gouge of the faults of the most recent series, particularly the White Caps

fault. In general realgar shows the same associations and mode of occurrence as the stibnite, and the two minerals are often found closely intergrown. In one specimen realgar was found in a cluster of little radiating rods, as if replacing stibnite.

Realgar occurs in quantity throughout the eastern ore body from the 300-foot level to the 665-foot level. Above and below this it is present only in minor amount.

Orpiment also occurs in the eastern ore body but only above the 400-foot level. It is clearly an alteration product of the realgar. All stages of the alteration process can be observed, beginning with threads of the orpiment in the realgar, through specimens showing cores of realgar surrounded by orpiment to pure orpiment. Only very rarely does orpiment occur, which is not clearly the result of alteration of realgar in place. In a few of the vugs in the coarse calcite there are delicate clusters of hair-like orpiment crystals.

The change from realgar to orpiment did not free any of the gold contained in the realgar. The orpiment is said to have about the same tenor as the realgar.

Later pyrite is found, particularly in the upper levels. This, like the stibnite and realgar, occurs in drusy open spaces in the dark quartz or more rarely along the cleavage faces of the white calcite. It is inconspicuous in amount compared to the stibnite and realgar. Marcasite has been reported, but its presence could not be definitely proved.

Among the later minerals of the deposits are minor amounts of quartz and calcite of a second generation, and rarely leverrierite. Small crystals of fluorite on projecting quartz crystals of one of the druses in the fine-grained quartz were observed on the 200-foot level.

Oxide minerals are nearly absent even in the upper levels. In the lower levels the waters flowing from the mineralized limestone are depositing stalactites and sludgy masses of limonite which contains arsenic, but whether as an arsenate or oxide is not known. In some of the stibnite specimens collected from the 100 and 200-foot levels there is a partial alteration to valenti-

nite and stibiconite. Microscopic crystals of a transparent mineral with high refractive index which may be arsenolite were observed in places, and pharmacolite is probably also present in small amount.

No free gold has been found in the White Caps mine. The bullion obtained from the cyanide process contains almost no silver, having a value of over $20 an ounce. The ratio of gold to silver is said to be about 17 to 1. The gold is clearly associated with the arsenical minerals, particularly the arsenopyrite. Possibly this explains its abnormal purity since arsenopyrite, realgar, and orpiment all tend to precipitate gold rather than silver from solutions.

Manhattan Consolidated.—The Manhattan Consolidated has been developed by five levels to a depth of 500 feet. The 100-foot and 500-foot levels were not accessible at the time of the writer's visit. The shaft cuts the overthrust fault below the 400-foot level. A normal fault of large throw, known as the Mud Fault, cuts the workings in a northeasterly direction and dips to the southeast.

The limestone bed is repeated on the 300-foot level, possibly by a reverse fault nearly parallel to the strike, and small faults of nearly northerly strike and small displacement are frequent. These are older than the faults of the northeast series, such as the Mud Fault. Motion parallel to the bedding is shown in gouge streaks along the top of the limestone.

The ore west of the fault is similar to that of the eastern part of the White Caps mine. The ore body is formed by the replacement of limestone on both sides of a small northerly fault. Coarse white calcite is prominent, particularly near the edges of the mineralized area. The best ore is a dark quartz much like that of the White Caps but containing only a little microscopic arsenopyrite and more pyrite. Stibnite is present in small amount, in drusy cavities in the dark quartz and in the limestone and calcite. Realgar is occasionally found. Small realgar crystals occur in the gouge along the Mud Fault, particularly near the surface.

The ore differs from that of the White Caps mine in that there is a considerable proportion of silver associated with the gold. Bullion from the eastern ore body is said to have a fineness of about 620.

The ore west of the Mud Fault differs markedly from that of the east ore body. Instead of a large replacement body, mineralization is closely associated with small fault fissures, giving the so-called "vein deposits." Four of these have been exploited; two follow northeasterly faults of small throw; another, less well defined, a fault nearly parallel to the strike of the limestone; and the fourth rather irregular mineralization along the top of the limestone. The mineralization does not extend for more than a few feet from the controlling fissure, and the ore shoots are small and irregular. Both coarse calcite and fine-grained quartz are present. These occur as replacements along the bedding of the limestone, thinning out away from the fissure. The quartz resembles that of the White Caps in texture, but is lighter in color, bluish gray rather than black. Pyrite is present, but arsenopyrite is lacking.

Irregular solution channels, in places following the dip of the limestone for 300 feet or more, are common in the limestone near the fissures. These contain deposits of muddy material, apparently chiefly limonite and manganese oxide, in which wire gold occurs.

Fluorite is plentiful in the ore west of the fault, in the larger cavities in the fine-grained quartz. Stibnite and realgar are absent in the western part of the mine.

Other Mines.—The same limestone bed outcrops to the westward from the Manhattan Consolidated along the crest and north side of Litigation Hill. The principal development has been done from the Bath and Earle shafts, and the Union No. 4 (Kane shaft). The deepest of these is the Earle shaft, which has followed the dip of the limestone for a distance of 700 feet. The mineralization is similar to that of the western part of the Manhattan Consolidated and is dependent upon the same types of small northerly faults. The northeasterly faults of larger throw

seem to be later than the period of mineralization marked by the coarse calcite and fine-grained quartz. The ore shoots are small and irregular, and it is said that no important bodies of workable ore were found at a depth greater than 300 feet on the incline.

Coarsely crystalline white calcite, fine-grained bluish quartz, and fluorite, and a little leverrierite, are the principal gangue minerals. The fluorite and leverrierite occur in cavities of the quartz. The quartz carries more or less pyrite, in grains barely visible to the naked eye, but apparently no arsenopyrite. Microscopic study revealed rare grains of adularia. The gold is contained in the fine-grained quartz, presumably in the pyrite, and also occurs as minute specks of free gold in the oxidized ore.

The same limestone follows the crest of April Fool hill until it is cut off by the overthrust fault. The limestone is extensively mineralized and has been mined for nearly the whole length of the outcrop. The high-grade ore, which gave the hill its fame in the early days of the camp, was apparently a near-surface phenomenon; most of the ore appears to have been taken out at depths of less than 30 feet, and no stoping extended below 100 feet.

The ore occurs along small faults which offset the limestone a few feet. Coarse calcite and fine-grained quartz appear as replacements of the limestone following the bedding plans irregularly for short distances from the fissures. The valuable ore, however, seems to be contained in small veinlets following these fissures. These consist chiefly of quartz and fluorite with a little calcite. The quartz carries free gold in places, and minute pyrite grains. Most of the coarse gold was found along the walls of the veinlets between the calcite and the wall rock. In places small rhombic crystals of adularia occur with the quartz.

On the northern side of the hill the limestone has been developed by several tunnels, the lowest being about 140 feet below the highest point of the outcrop. Here the ore is of different character. The rich ore of the surface workings is lacking, and that extracted has seldom yielded over $20 per ton. The mineralization takes the form of an irregular replacement of limestone

extending outward from small fissures. For the most part the ore is similar to that of the mines on Litigation Hill, except for a higher proportion of fluorite. In places, particularly in the lowest tunnel, there are large, irregular caverns in the limestone, which may be lined with large fluorite crystals. Commonly, however, the roof and walls show large numbers of white inverted domes, up to about 6 inches in diameter. These consist of alternate layers of fine-grained white quartz and white clayey material of sericitic appearance, the optical properties of which correspond to leverrierite, a hydrous aluminum silicate. The leverrierite layers are rarely pure and commonly contain large numbers of little grains of quartz and chalcedony scattered through them. More rarely crystals of fluorite are inclosed in the leverrierite. A few pseudomorphs of limonite after pyrite also occur in the leverrierite. This material carries a small amount of gold, said to be about $4 per ton.

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Upper Limestone Ores.—The upper limestone beds, near the top of the Cambrian, have been prospected extensively but contain ore only on the Mustang claim close to the overthrust fault. The limestone here shows the effects of contact metamorphism and is largely altered to diopside. Gold has been obtained close to the surface from little fissures, similar to the veinlets which yielded the rich surface ore on April Fool Hill, and small replacement veinlets carrying quartz and fluorite. Small flakes of barite were also found in the concentrates from this ore. Most of the production, however, has come from peculiar pipe-like ore shoots which follow the dip of the limestone, usually along the intersection of a bedding plane with a well-developed joint plane or small fault. These pipes are nearly circular in cross section and from 8 inches to 2 feet in diameter. Around each is a rim of fine-grained white quartz, a couple of inches thick. The interior of the pipes is composed of a soft white material, with the same silky luster characteristic of sericite. The optical properties, however, were found to agree more nearly with the mineral leverrierite, a hydrous aluminum silicate, with the for-

mala $Al_2O_3.2SiO_2.2\frac{1}{2}H_2O$.[14] The following partial analysis, made by R. K. Bailey, of the U. S. Geological Survey, confirmed this determination.

	Per Cent.
H_2O — 100	4.56
H_2O + 100	16.15
K_2O	0.31

Small grains of quartz occur intimately mixed with the leverrierite, and it was found impossible to separate sufficiently pure material to warrant a complete analysis. Specks of limonite scattered irregularly through the pipe represent original pyrite. Free gold occurs throughout the leverrierite, in sufficient amount to have yielded over $40,000 in a distance of about 100 feet along the pipe. The gold is mostly very fine, but occasionally occurs as round pellets which look like small shot. As far as could be determined from microscopic examination, the gold is in all cases surrounded by the leverrierite and has apparently no close association either with the oxidized pyrite or disseminated quartz.

The principal pipe has been followed down the dip of the limestone for about 100 feet. Several smaller pipes branching upwards from the main pipe were encountered but not developed. The richest spots were said to have been at the intersections of the main pipe with its branches. The lower workings were not accessible at the time of the writer's visit, but it is said that at depth the pipes became less well defined and difficult to follow.

MINERALOGY.

Distribution and Paragenesis.—The following table illustrates the principal variations of the perplexing variety of limestone ores encountered as one crossses the district from east to west, along a distance of about 2 miles. For comparison the ores of the schists have also been included:

[14] Larsen, E. S., and Wherry, E. T., "Leverrierite from Colorado," *Jour. Wash. Acad. Sci.*, vol. 7, pp. 208–217, 1917.

TABLE SHOWING PRINCIPAL MINERALS PRESENT IN THE LIMESTONE ORES.
Bold face and parentheses indicate relative importance or scarcity, respectively.

	Native Gold.	Arsenopyrite.	Pyrite.	Stibnite.	Realgar.	Orpiment.	Fluorite.	Quartz.	Calcite.	Leverrierite.	Adularia.	Barite.
White Caps { Eastern part.		X	(X)	(X)	**X**	X		**X**	**X**			
White Caps { Western part.		X	(X)	**X**	(X)		(X)	**X**	**X**	(X)		
Manhattan Con. { Eastern part.		(X)	X	X	(X)		X	**X**	X	(X)		
Manhattan Con. { Western part.	X		X				**X**	**X**	X	X		
Litigation Hill	X		X				**X**	X	X	X	(X)	
April Fool Hill	X		X				**X**	X	X	**X**	X	
Mustang	X		(X)				X	X	(X)	**X**	X	(X)
Sunset prospect			X	**X**				X	(X)			X
Schist ores	X		X					**X**	(X)		**X**	

The paragenesis of the principal minerals of the limestone mines appears to be as follows: (1) Coarsely crystalline white calcite, (2) fine-grained quartz containing, in the White Caps mine, contemporaneous arsenopyrite and elsewhere pyrite. In some deposits a little adularia appears to have crystallized contemporaneously with the quartz. (3) Fluorite and leverrierite and rare adularia, found chiefly in the eastern deposits. In places quartz and leverrierite are closely intergrown. (4) Stibnite and realgar are of distinctly later date, together with later pyrite, quartz and calcite. All the ores of the first group though later than the first period of faulting, and are older than the most recent movement along the major faults. The realgar and possibly the stibnite on the other hand were introduced subsequently to the second period of faulting. It appears therefore that in the White Caps and the eastern part of the Manhattan Consolidated mines, at least, there is a superposition of two or more periods of mineralization of widely separated ages.

The ores show great variance in character along the same bed of limestone. Leverrierite is prominent on April Fool Hill and in the higher limestone on Mustang Hill, and is nearly lacking at the eastern end of Litigation Hill; fluorite also decreases to the eastward, though it is found in the Manhattan Consolidated,

and very rarely in the White Caps. The fine-grained quartz, on the other hand, is more prominent in the eastern mines. Arsenopyrite is largely confined to the White Caps, though it may be present in small amount in the dark quartz of the Manhattan Consolidated. Pyrite is persistent throughout, but is less prominent in the White Caps than the other mines. The coarse calcite occurs throughout and indeed is not confined to the vicinity of the ores, but seems to occur sporadically in all the limestones, particularly where fissured.

The difference in the ores along so short a distance is probably due in large measure to changing character of the solutions along the strike. It may be also to some extent, due to differences in original vertical position. The larger faults have their downthrow sides to the eastward, hence at the time of the deposition of the first series of minerals the White Caps stood highest, followed by the eastern part of the Consolidated and the Litigation Hill mines, and lastly April Fool Hill, which was much lower than the White Caps at the time of the ore deposition, though there is no way of determining how much of the displacement is due to post-mineral faulting.

The stibnite of the limestone mines is believed to be of later date. That stibnite should be confined to the limestone and nowhere present in the neighboring schist is probably due to the influence of the country rock, since the waters passing through the limestone would contain bicarbonate, which would precipitate stibnite from an alkaline solution.

Realgar: Occurrence and Origin.—Realgar is found in notable amount only in the White Caps mine, where it occurs in the same general manner as stibnite. It is, however, rather more migratory in its distribution, since it is found in the schist at some distance from the limestone, and small crystals of realgar have formed in the gouge accompanying the later series of faults, whereas stibnite is rarely found in these positions. Realgar and stibnite are in places found closely intergrown, and it is believed that they are approximately contemporaneous, although in one specimen realgar appears to have replaced stibnite. Realgar is

found only where the dark quartz carries arsenopyrite and not in those mines in which pyrite is the principal metallic mineral. It occurs in quantity in the White Caps mine, only down as far as the 665-foot level. Below this the ore consists of very cavernous dark quartz, brecciated and crumbly in places, with occasional patches and scattered crystals of realgar. Dynan[15] has suggested that the realgar is a secondary mineral derived from the arsenopyrite. The fact that realgar is confined to the White Caps mine, which is the only mine in which arsenopyrite is present in notable amount, renders this supposition extremely probable. Normally, under the action of oxidizing waters, scorodite or pharmacosiderite should be the end point of oxidation of arsenopyrite.[16] There appear to be numerous instances, however, in which realgar is a secondary sulphide,[17] and Lindgren[18] even says:

"Realgar and orpiment are probably always supergene sulphides but they are not found in the secondary zones of copper deposits. They are rather more characteristic of the oxidized zone, and often are derived from arsenopyrite. The chemistry of their deposition is uncertain."

It is possible that the method of formation of supergene realgar from arsenopyrite is analagous to the formation of sulphur in the first stages of the oxidation of pyrite. Stokes[19] gives the following equation:

$$FeS_2 + Fe_2(SO_4)_3 = 3FeSO_4 + 2S.$$

The equivalent reaction in the case of arsenopyrite would be:

$$FeAsS + Fe_2(SO_4)_3 = 3FeSO_4 + AsS.$$

Stokes, however, did not obtain arsenic sulphide when arsenopyrite was treated with ferric solutions.[20]

[15] Dynan, *op. cit.*, p. 885.

[16] Lindgren, W., "Mineral Deposits," p. 898, New York, 1919.

[17] Emmons, W. H., "The Enrichment of Ore Deposits," Bull. U. S. G. S. No. 625, p. 466, 1917.

[18] *Loc. cit.*, p. 899.

[19] Stokes, H. N., "On Pyrite and Marcasite," U. S. Geol. Survey Bull. 186, p. 15, 1901.

[20] *Loc. cit.*, p. 33.

In this case, moreover, the realgar is not confined to the zone in which oxides occur but is found to the lowest depth yet explored, though only prominent above the 665-foot level.

The similar mode of occurrence of the realgar and stibnite suggests another possible explanation. If, as appears to be the case, the stibnite is distinctly later than the quartz and arsenopyrite it is possible that the hypogene solutions, presumably deficient in oxygen, which deposited the stibnite also attacked the arsenopyrite. The arsenic thus dissolved would be deposited as realgar in the zone where the ascending waters began to be contaminated with the bicarbonate of the supergene waters of the limestone.

The fact that sibnite is barren and the realgar gold bearing is perhaps additional evidence of the secondary origin of the realgar. For if the realgar were derived from the arsenopyrite the gold present in the arsenopyrite would tend to migrate with the arsenic to the realgar, while if both stibnite and realgar were of hypogene origin and contemporaneous, it would not be expected that the gold would be present in only one of the two minerals.

On the other hand realgar has often been found in hot spring deposits, and there is no inherent reason why it should not be found as a primary mineral in ore deposits formed at shallow depth. In the microscopic examination of the White Caps ore, the writer has not been able to find any clear evidence of alteration in place of arsenopyrite to realgar. The large amount of realgar found between the 400 and 660-foot levels would require the alteration of an enormous amount of arsenopyrite, and there is no evidence of any marked leaching of the arsenopyrite in the upper levels. There is a small amount of later pyrite, apparently contemporaneous with the realgar and stibnite but not at all comparable in volume to the realgar. It may be, however, that an iron-rich gossan has been eroded.

Oxidized Minerals.—The amount of oxidation, particularly in the deposits in the limestone, is comparatively small. In the White Caps and Manhattan Consolidated mines slightly oxidized stibnite occurs in the surface workings. The oxidized antimony

minerals are inconspicuous and cannot everywhere be certainly identified. The principal ones appear to be valentinite and stibiconite. The latter appears to have formed both directly from the stibnite and as an alteration product of the valentinite. Palmer[21] records the presence of kermesite as well. Except for rare minute grains of what may be arsenolite in ore from the upper levels of the White Caps and the presence of arsenic in the limonitic material deposited on the walls of the drifts, no oxidized arsenical mineral has been recognized. In the pyrite-bearing ores of the schists, on the other hand, the pyrite has in places been altered to limonite to depths of 300 feet or more.

Orpiment: Occurrence and Origin.—Orpiment, which is found in the upper 400 feet of the eastern ore body of the White Caps, is clearly derived from realgar, presumably by the action of oxidizing waters. Specimens can be collected which show all stages of alteration, from the first development of threads of orpiment along little cracks in the realgar through cores of realgar, surrounded by orpiment, to pure orpiment. It is difficult to understand why the change from realgar should be to a mineral with higher sulphur content (AsS to As_2S_3), without the formation of oxidized arsenical minerals at the same time. In the lower levels of the mine, however, below the zone in which the orpiment occurs, the mine waters flowing from fissures near the ore are depositing a limonitic sludge on the walls of the drifts. Qualitative tests show the presence of considerable arsenic in this material. Apparently orpiment is the stable sulphide under surface conditions, and the alteration takes place through oxidation of a part of the arsenic of the realgar rather than of the sulphur. This is soon redeposited in association with iron oxide; whether as oxide or an iron arsenate has not yet been determined. An analogous reaction is that by which chalcocite changes by oxidation to covellite.[22]

The alteration of the realgar to orpiment takes place with

[21] Palmer, W. S., "Formation of Quicklime in Roasting Ores from Manhattan, Nev.," *Mining and Engineering Journal*, vol. 104, p. 525, Sept. 22, 1917.

[22] Lindgren, W., *op. cit.*, p. 859.

comparative rapidity in the sunlight. Fragments of realgar left on the mine dump soon lose their bright red color due to the formation of a thin coating of orpiment. A small amount of pure realgar was placed under glass in the sunlight. Incipient alteration was noticed within a few days and in a few weeks the transformation to orpiment was well advanced. No recognizable arsenic oxides were found, though according to Dana[23] realgar alters in the light to orpiment and arsenolite.

To test the probability of the alteration of realgar to orpiment by oxidizing waters small amounts of realgar were placed in a dilute solution of ferric sulphate and gently heated. The realgar was in part altered to orpiment and arsenic oxide.

The hair-like crystals of stibnite and orpiment, which are sometimes found, suggest supergene sulphide deposition. C. Doelter[24] states that stibnite at 80° is slightly soluble in water and that recrystallization is also perceptible.

Gold.—At least a part of the gold in the rich surface ores is due to secondary deposition. No free gold has been found in the White Caps or eastern ore body of the Manhattan Consolidated. In the White Caps, and probably to some extent in the Consolidated also, the gold is present in the minute arsenopyrite crystals scattered through the dark quartz. The stibnite is barren, but the realgar and orpiment are both gold bearing, so it is apparent that in whatever form the gold is present in the arsenopyrite, it has remained with the arsenic through the succcessive changes from arsenopyrite to realgar and thence to orpiment. In the western part of the Manhattan Consolidated and in the Litigation Hill mines, free gold occurs as small flakes in sandy material consisting of minute fragments of quartz and calcite with manganese and iron oxides in irregular solution channels in the limestone. This was probably derived from the pyrite of the massive quartz and deposited by supergene waters. The rich

[23] Dana, E. S., "System of Mineralogy," p. 34, 1895.

[24] *Min. pet. Mitt.*, vol. 11, 1890, p. 322, cited by F. W. Clarke, "Data of Geochemistry," U. S. Geol. Survey Bull. No. 616, p. 689, 1916.

surface ores of the workings on April Fool Hill, in which the gold occurs in close association with calcite, are apparently due to secondary enrichment. These were very rich close to the surface, but nearly barren at shallow depth. Gold carried in acid surface waters would be quickly deposited in contact with calcite and superficial enrichment could not extend to any appreciable depth.

Secondary enrichment appears to have played a much more important part in the ores of the schists than in those of the limestones. In these deposits the richest ore is commonly found at the intersection of the principal vein with small fissures rich in manganese oxide. Since calcite is lacking in these deposits the lower limit of enrichment is at a greater depth than in the ores of the limestone, but rich ore does not seem to have been mined below about 200 feet. In the schist mines such as the Big Pine, where the gold occurs in a multitude of small stringers in the schist, there is little manganese oxide and no clear evidence of secondary enrichment.

RELATION OF ORE DEPOSITION TO FAULTING.

The productive mines of the district all lie in a belt extending about 10,000 feet from east to west and less than 2,000 feet from north to south. The overthrust fault marks the northern limit of productive mineralization. This fault is older than the numerous normal faults which cut the ore-bearing limestones and is undoubtedly contemporaneous with the intense folding which preceded the intrusion of the granodiorite.

Movement on the normal faults may have begun at the time of the granodiorite intrusion for an alaskite dike seems to follow one of the faults. The major normal faulting, however, probably did not take place until late Tertiary time, subsequent to the intrusion of the andesite porphyry.

Productive ore deposits occur only close to the overthrust fault, and along the southern or hanging wall side. Although the actual fault plane is nowhere mineralized, it is believed that

the presence of this major fault was the determining factor in the localization of the deposits. The mines are all on the hanging-wall side of the overthrust and for the most part associated with the small normal faults of later date. It may be that the overthrust fault with its narrow zone of comparatively impervious gouge acted as a dam to prevent important migration of the solutions north of the fault, and that the intersection of the overthrust with the minor normal faults determined the principal channels followed by the ascending solutions. This furnishes a possible explanation for the localization of mineralization in the White Caps limestone, to the exclusion of the two similar beds at slightly lower horizons. The limestones at the White Caps mine and on Litigation Hill, while approximately parallel with the overthrust in strike, have a slightly steeper dip. Thus the White Caps limestone would be cut by the fault plane at a lower level than the two lower beds and uprising solutions controlled to the north by the overthrust would tend to be diverted along the first soluble bed.

AGE OF THE ORES.

Ores of deep origin and those characterized by minerals indicative of deposition at shallow depth are both represented in the Manhattan district. The former are represented by the small glassy quartz veins found here and there throughout the district. These veins seem to be clearly associated with the granodiorite intrusion, probably most closely with the final phase which produced the aplite dikes. Productive deposits of the same epoch have been mined within a few miles of Manhattan.

The small veins of the lavas and the veins in the schists of Gold Hill, on the other hand, show certain characteristics of veins formed at shallow depths, such as adularia and quartz pseudomorphic after lamellar calcite. Since ores of this type occur in the post-Siebert andesite, these veins can be assigned to a period between the late Miocene and the formation of the late Pliocene erosion surface. Presumably this period of ore deposition is genetically connected with the andesite intrusion.

The ores of the limestone are more complex and lack minerals or mineral associations clearly diagnostic of either of the above groups, and it is likely that more than one period of mineralization is represented.

Dynan[25] considers that the ore of the White Caps mine owes its origin to solutions emanating from the intrusive granite.

Outcrops of granitic rocks occur much nearer the mines than do the Tertiary igneous rocks. On the hill north of Litigation Hill there are two small dikes of a coarse-grained alaskite, and several small aplite dikes cut the sediments a short distance to the south. Two small masses of a much sericitized igneous rock, probably an aplite, have been encountered in the lowest level of the White Caps.

The coarse calcite, usually associated with some valuable mineralization, occurs in places close to the granodiorite and Dynan mentions[26] specimens of coarse calcite and garnet from the granodiorite contact which assayed 0.03 oz. gold per ton. Similar coarse calcite in the silver-lead deposits of the Darwin district, California, has been described by Knopf.[27] There it seems to be directly connected with an intrusion of granodiorite. On the other hand, this type of calcite is not present in limestones of the Belmont and Barcelona districts where the occurrence of the ore is clearly related to the presence of the granodiorite.

Leverierrite is present in all of the ore deposits in the limestone. This mineral is uncommon in ore deposits but was found by Larsen and Wherry[28] in quartz veins with manganese oxide. Racewinite from the Highland Boy mine of Bingham, Utah, described by A. N. Winchell[29] appears to be identical with leverrierite.[30] Here it occurs in ores associated with a monzonite porphyry intrusion.

[25] *Loc. cit.*, p. 885. [26] *Idem*, p. 885.

[27] Knopf, A., "The Darwin Silver-Lead Mining District, California," Bull. 580, U. S. Geol. Survey, p. 7, 1915.

[28] Larsen, E. S., and Wherry, E. T., *loc. cit.*, p. 217.

[29] Winchell, A. N., "Racewinite, A Peculiar Mineral from Ore Deposits in Utah," Econ. Geol., vol. 13, pp. 611–615, 1918.

[30] Butler, B. S., "Ore Deposits of Utah," Prof. Paper No. 111, U. S. Geol. Survey, p. 113, 1920.

It is believed, however, that the weight of the evidence favors the probability that these ore deposits were formed fairly close to the surface and are of Tertiary age. The deposits are absolutely unlike those of Belmont and Barcelona, in which the primary ore consists of sulphides such as galena, sphalerite, tetrahedrite, and chalcopyrite in a quartz-calcite gangue, nor is there any similarity between these and the small unproductive veins of deep-seated origin found here and there throughout the Manhattan district. The large amount of fluorite likewise is considered indicative of deposits of the shallow rather than of the deep vein zone. Moreover, the presence of a little adularia intergrown with the fine-grained quartz is believed to form a connecting link with the quartz adularia veinlets of Gold Hill which clearly belong to the class of veins formed at shallow depth. Also the fine-grained drusy quartz suggests deposition nearer the surface than the coarsely crystalline quartz and sulphides of the ores of Belmont.

The principal minerals of the limestone deposits, quartz, fluorite, leverrierite, arsenopyrite, appear to have been deposited prior to the most recent movement along the larger faults. The stibnite and realgar, on the other hand, are younger than the latest faulting and appear to represent a still later period of Tertiary ore deposition. It is probable that there were two periods of late Tertiary mineralization, probably both subsequent to the intrusion of the andesite porphyry. It is possible, however, that the coarsely crystalline calcite may be a representative of the mineralization following the granodiorite intrusion.

CONCLUSIONS.

The productive mines of the Manhattan District occur close to large overthrust fault and are all in the upper or overthrust block. Although no ore deposition occurred in the fault plane itself, the presence of this fault is believed to have been the controlling factor in localizing ore deposition. Particularly favorable situations appear to be in localities where late normal faults

displace the overthrust. Two series of normal faults are recognized, the first, characterized by small throw, steep dip, and general direction about north-northeast, and the other with generally larger throw, flatter dip and less accordant strike. While the two series may be of contemporaneous origin, there has been more recent movement along the faults of the second group. The faults of the first group may have been initiated by the intrusion of the granodiorite batholith, but the more important faulting is tentatively correlated with the intrusion of a mass of andesite porphyry of late Miocene or Pliocene age.

The ore deposits show a wide variety. Small quartz veins in the schists, with pyrite, chalcopyrite, tetrahedrite, and galena, have not proved workable. These are clearly of deep-seated origin and may be correlated with the granodiorite intrusion and are presumably late Cretaceous or early Eocene in age. The ores of the Cambrian schists show a mineral association characteristic of shallow zone deposition and may be genetically connected with the andesite porphyry. The characteristic minerals of these ores are quartz, in small comby veinlets, and pseudomorphic after tabular calcite, adularia, pyrite and free gold.

A bed of crystalline limestone occurring in the lower part of the Cambrian is heavily mineralized and shows a complex association of minerals. At the eastern part of the district the principal gangue minerals are coarse calcite and fine-grained quartz, and the metallic minerals arsenopyrite, pyrite, stibnite, realgar and orpiment. The ore occurs in large replacement deposits in the limestone closely connected with the faults in the earlier series. Stibnite, realgar, and orpiment, however, are later than the second series of faults. It is believed that the deposition of stibnite was due to a later period of ore deposition, and that the realgar is secondary and derived from the arsenopyrite, though possibly through the action of hypogene solutions. The orpiment has been derived from the realgar through the oxidation of a part of the arsenic.

The character of the ore changes greatly to the westward along the strike of the limestone bed. Arsenopyrite is not present in

the quartz, and realgar and orpiment are no longer found. Stibnite is present only in one other deposit. Free gold, lacking in the White Caps ore, is found farther to the westward, fluorite and leverrierite become increasingly important gangue minerals, and minor adularia is present.

It is possible that three periods of mineralization are represented in the limestone ores; one marked by coarsely crystalline white calcite, which may have followed the granodiorite intrusion, and if so is of late Cretaceous or early Eocene age; the second, which introduced the quartz, arsenopyrite, pyrite and gold, together with the fluorite and leverrierite, is of later date, but prior to the most recent faulting; and the third, characterized by the stibnite and the realgar of the eastern part of the district, is still younger.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.

DETERMINATION OF ATTITUDE OF CONCEALED BEDDED FORMATIONS BY DIAMOND DRILLING.

WARREN J. MEAD.

In diamond drilling operations it occasionally becomes necessary to determine the attitude of bedded formations which are concealed beneath glacial drift or wash, or by younger beds lying unconformably above. If the concealed beds are closely folded and contorted and their dip and strike vary within short distances, their attitude must be described in terms of folds and can only be determined by a large amount of drilling with very careful interpretation. The present article deals with concealed beds which are tilted but not contorted and in which the dip and strike do not vary abruptly. If the concealed beds are flatlying, their attitude is disclosed by a single vertical diamond-drill hole. This statement assumes that it is known that the beds are not closely folded. A vertical hole striking the axis of an anticline in closely folded beds might be interpreted as having encountered flatlying beds. The knowledge of the structural geology of the rocks in the vicinity, however, should in most cases enable one to predict, with a fair degree of certainty, the type of structure to be encountered in the drilling.

If drilling discloses a "marker," such as an easily recognized bed or contact in the formation, the attitude of the beds can be determined from three drill holes in which this "marker" horizon is pierced. The three points determine the plane of the "marker" horizon and by graphical methods the attitude of this plane can easily be determined. The present article deals with the common condition in which no "marker" horizon is found and in which the only datum is the relation of the plane of the bedding to the axis of the drill hole.

If the concealed beds are inclined, the attitude of the bedding

as observed in the core from a vertical diamond-drill hole gives the angle of dip but since the core cannot be removed from the hole without losing its orientation relative to horizontal directions, the strike of the beds cannot be determined by observations on the core. Core from an inclined diamond-drill hole in the immediate vicinity gives the angle which the beds make with the axis of that hole. If, by chance, the inclined hole is drilled in a vertical plane which is *perpendicular to the strike,* the direction of strike can be recognized, since the angle which the bedding makes with the axis of the inclined hole is either the sum of the angle of inclination of the hole (measured from the vertical) and the complement of the angle of dip or the difference between these two angles. (See Figure 7.) If the inclined hole is drilled

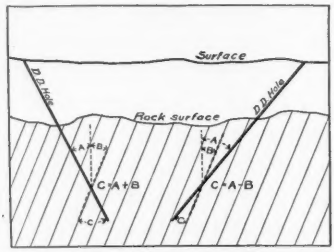

FIG. 7. Cross-section normal to strike of concealed bedded formations. Two inclined diamond-drill holes are in the plane of the cross-section. A = angle of inclination of hole measured from vertical. B = complement of the angle of dip. C = angle of beds with drill hole.

in any other vertical plane the relationships are not so simple and depending on the angle and direction of the inclined hole, two, three or four possible directions of strike are obtained from the data of the two holes. In such cases a second inclined hole is necessary in order to definitely determine the strike and the direction of dip. This second inclined hole should not be parallel to the first one; if parallel it is equivalent to the first one and yields no new data.

The various possibilities present an interesting series of prob-

lems and lead to certain definite conclusions as to the best method of locating the inclined hole for the purpose of determining the attitude of the concealed beds. In Figure 8 an attempt has been made to illustrate in isometric projection a vertical hole and an inclined hole which intersects the vertical hole somewhere within the concealed beds. Since only the vertical axis of the core from the vertical hole is known, a given bedding plane can only be defined as a tangent to a vertical cone, the axis of which is the

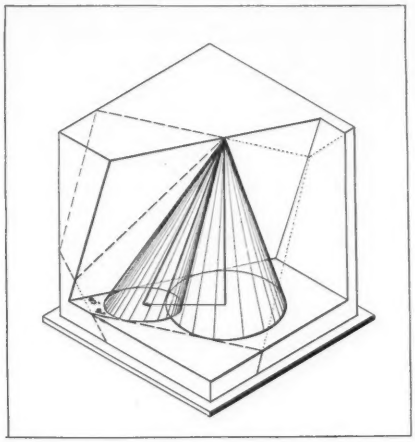

FIG. 8. Isometric projection showing an inclined and a vertical diamond-drill hole as axes of a vertical and an inclined cone respectively with the common tangent planes of these two cones.

vertical drill hole, and the vertical angle twice the angle which the bedding plane makes with the axis of the hole.

This vertical cone is represented in the diagram, and its intersection with any horizontal plane, such as the base of the diagram, is a circle. The inclined hole gives the angle which the bedding plane makes with its axis and it may be said that the bedding plane is a tangent to an inclined cone having the inclined hole as an axis and a vertical angle of twice the angle which the bedding makes with the axis of the inclined hole. This inclined hole is

also represented in the diagram, and its intersection with the horizontal plane is an ellipse. Now from the foregoing and referring to the illustration, it appears that the position of the bedding plane must be that of a common tangent plane to the two cones and it is also evident that there are two, and only two, such planes under the conditions represented in the diagram. Furthermore, it is seen that the two possible directions of strike (the direction of the lines of intersection of these two tangent planes

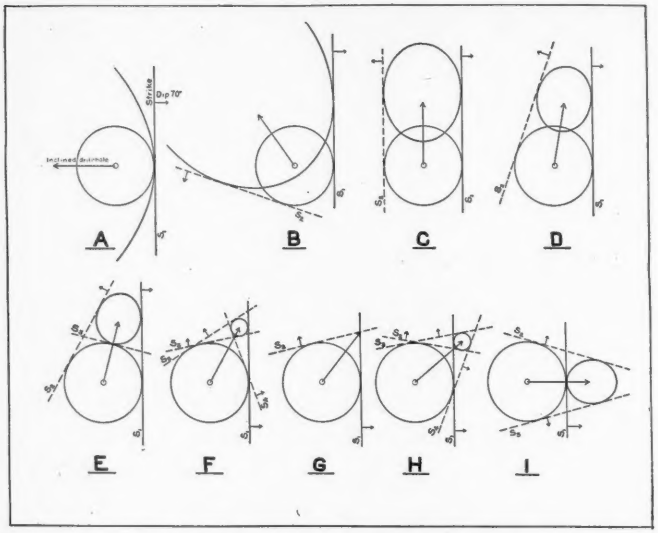

FIG. 9. A series of cases arising when the inclined hole is drilled at an angle flatter than the dip.

and the horizontal plane) are tangent to the circle and the ellipse formed by the intersection of the two cones with the horizontal plane.

The circle and ellipse with the two tangent lines as shown in Fig. 8 are represented in plan in Fig. 9D. The other cases in Fig. 9 lettered from A to I inclusive show the various conditions arising as the inclined hole is drilled in progressively varying

directions with respect to the strike. These can best be understood by referring back to Fig. 8 and visualizing the various inclined cones which would be developed about the inclined hole as its direction is changed. In all of the cases illustrated in Fig. 9 the dip and strike and the inclination of the inclined hole are constant. The only changing feature is the direction of the inclined hole with respect to the strike.

In case "*A*" the inclined hole is drilled in a vertical plane which is normal to the strike and in a direction opposite to the dip. The inclined hole has the largest possible vertical angle and its intersection with the horizontal plane may, in general, be any one of the three types of conic-sections. Since the vertical and inclined cones are tangent in this case, there can be only one tangent plane.

In case "*B*" the inclined hole is assumed to be drilled in a vertical plane at an angle of 35° with the strike and away from the direction of dip. There are two planes tangent to both cones whose horizontal traces are marked S_1 and S_2. A special case may arise where the direction of the vertical plane of the inclined hole is such that the two tangents are at right angles.

In case "*C*" the inclined hole is shown in a vertical plane which is parallel to the strike. The horizontal traces of the two tangent strike planes are in this case parallel. Such a condition gives the strike but not the direction of dip.

In case "*D*" the inclined hole is in a vertical plane, making an angle of 15° with the strike and is drilled in the direction of dip. The two possible directions of strike resulting converge in the direction of the inclined hole.

In "*E*" a special case is illustrated in which the inclined cone is tangent to the vertical cone and three tangent planes common to both cones are possible. Their horizontal traces give three possible directions of strike.

In case "*F*" the inclined hole is drilled in a vertical plane which makes an angle of 30° with the direction of strike and in the direction of dip. The inclined cone is smaller and does not intersect the vertical cone. This condition makes possible four

common tangent planes to the two cones with horizontal traces representing four possible directions of strike.

In case "*G*" the inclined hole is drilled in a direction that causes it to follow the planes of bedding. The inclined cone consequently becomes a line, and there are two possible tangent planes of the vertical cone containing this line, and, two resulting directions of strike are shown by the horizontal traces of these planes.

In case "*H*" the inclined hole is drilled so far in the direction of dip as to intersect the beds from below, that is, if the beds are not overturned, the hole passes from older to younger beds. The angle of the bedding in the inclined hole is small and the cones do not intersect. This results in a case very similar to *F*, the only difference being that in *F* the beds are cut from younger to older and in *H* the reverse is the case. If the top and bottom of the beds can be determined from a careful study of the core, these two cases can be discriminated.

In case "*I*" the inclined hole is drilled in a vertical plane which is normal to the direction of strike and in the direction of the dip. The inclined cone is necessarily tangent to the vertical cone and there are three possible directions of strike. This case is very similar to case *E*, the only difference being that in *E* the beds are intersected in normal succession while in *I* they are intersected in the inclined hole from below upward.

It should be noted that in successive cases in Fig. 9 the inclined cone (and hence the angles which the bedding planes make with the inclined hole) becomes progressively smaller, reaches a minimum in case G, and then increases.

The various cases which arise when the inclined hole is drilled at the same angle as the dip are illustrated in Fig. 10. In this figure as in Fig. 9 the intersections of the horizontal plane with the vertical and inclined cones and their common tangent planes are shown. In all cases represented the dip and strike of the beds and the inclination of the inclined hole are the same. In cases *A*, *B*, *C* and *D* situations are essentially the same as in the cases similarly designated in Fig. 9 and the same discussion may be

applied. In the last case, *E*, the inclined hole is drilled in a vertical plane perpendicular to the strike and in the direction of the dip. The hole consequently follows the bedding and the in-

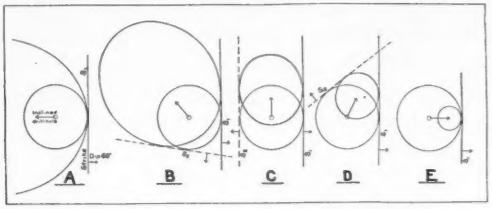

FIG. 10. Various cases arising when the inclined hole is drilled at the same inclination as the dip of the beds.

clined cone becomes a line on the surface of the vertical cone. The direction of strike is definitely determined in this case, as there is only one tangent common to the vertical cone and the line of the inclined hole.

In Fig. 11 a series of cases is illustrated which arises when the inclined hole is drilled at a steeper angle than the dip. All five of the cases represented are essentially like the five cases illus-

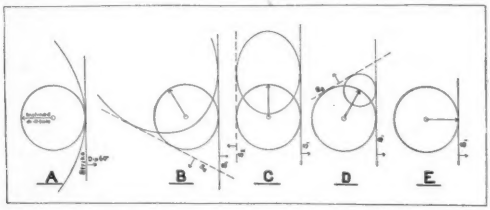

FIG. 11. The various cases arising when the inclined hole is drilled at an angle steeper than the dip of the beds.

trated in Fig. 10, except that in case "*E*," in which the inclined hole is drilled in a vertical plane which is normal to the dip and in the direction of the dip, the resulting inclined cone is tangent internally to the vertical cone.

From the foregoing it is seen that when the inclined hole is drilled at an angle flatter than the dip of the beds, as many as

four possible directions of strike may result from study of the data from the two holes. In such a case there is only one chance in four of choosing the true direction of strike and locating the second inclined hole in a vertical plane normal to this direction to be drilled in a direction opposite to the direction of dip.

When the inclination of the inclined hole is equal to or steeper than the dip of the beds only two possible directions of strike can result and usually it is possible to select one of these as being the most probable.

When the dip of the beds is found to be very steep, that is, above 75° or 80°, the necessary error of observation of the angle of the bedding on the drill core when such small angles are dealt with makes it inadvisable to drill the inclined hole at such a steep angle.

When the concealed beds are vertical, only two probable directions of strike are found and the direction of dip becomes a matter of determining the top and bottom of beds in the inclined hole.

GRAPHICAL METHOD OF SOLVING THE PROBLEM.

A vertical hole and an inclined hole are shown in plan at points *A* and *B* respectively in Fig. 12. In the same figures these holes are shown as projected onto a vertical plane as *A–o* and *b–d'*. The vertical plane on which these holes are shown in projection is taken parallel to the vertical plane containing the inclined hole. For purposes of solution the inclined hole is moved to the point *B'*, this location being chosen because the inclined hole will then intersect the vertical hole within the rock formation. The vertical projection of the inclined hole in its new position is *B'–n*. The angle which the bedding makes with the core in the vertical hole is *oxh* and the angle which the bedding makes with the inclined hole is *pxm*. $\angle oxh = \angle oxg$. $\angle pxm = \angle mxr$. The line *CD* is the trace of a horizontal plane. The vertical and inclined cones are shown in cross-sections as *gxh* and *pxr* respectively. By rotating the horizontal plane on its trace *CD* into the plane of the paper the horizontal sections of the two

cones may be developed. The horizontal section of the vertical cone is a circle with its center at *O* and a radius *oh*. The horizontal section of the inclined cone is an ellipse whose major axis is *pr*. The minor axis is found by passing a plane through the inclined cone perpendicular to its axis so as to contain the minor axis of the ellipse. This section is a circle and upon rotation of the plane into the plane of the paper it appears as a

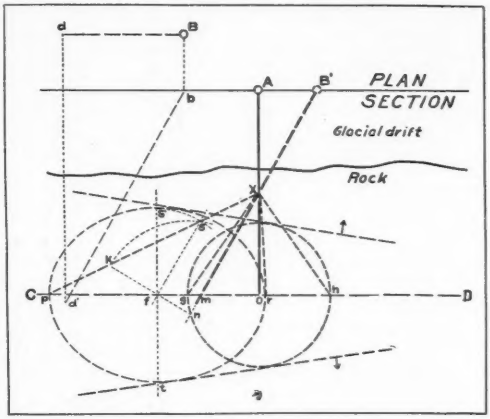

FIG. 12. Graphical solution of the problem.

circle with its center at *n* and its radius *nk*. The length of the minor axis is a chord of this circle *fs* which is rotated about the point *f* to its proper position *S'* at right angles to the major axis. From the major and minor axes the ellipse can readily be constructed. Lines drawn tangent to the circle and the ellipse are traces of tangent planes common to the two cones and represent the two possible directions of strike and dip, the dip being away from the vertical hole.

MECHANICAL SOLUTION OF THE PROBLEM.

For mechanical solution of this problem the writer devised the apparatus shown in Fig. 13. A circular base is mounted on three leveling screws. The rod *A* represents an inclined hole and by

means of the graduated arc *B* this rod may be set at any angle of inclination to represent any inclined drill hole. The rod is mounted to rotate about a vertical axis and the direction of the drill hole may be properly represented by means of the pointer on the graduated circle *C*. The plane surface *D* is mounted to swing on an axis at right angles to the rod which represents the inclined hole and by means of the graduated arc *E* this plane may be set at any angle to the rod to represent the angle which

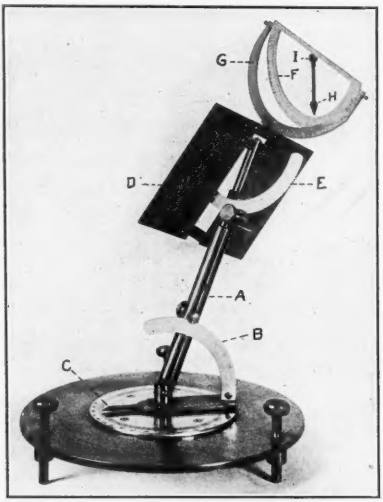

FIG. 13. Apparatus for determining the attitude of concealed beds from diamond drill data.

the bedding makes with the inclined hole. The rod is so constructed that by means of a telescoping section its upper portion may be rotated on its axis and consequently the inclined plane may be turned to any position on the axis of the rod, always, however, maintaining the same angle with the rod. The graduated half-circle *F* is pivoted to the semi-circular hanger *G* and the pointer *H* acts as a plumb-bob, being delicately supported at *I*. By virtue of this construction the graduated half-circle *F*

always seeks a vertical plane which is always at right angles to the direction of the strike of the plane surface. The plumb-bob consequently at all times shows the dip of this plane surface as it is rotated about the axis of the rod. The dip of the beds has been determined from the core from a vertical hole and consequently when the surface *D* is rotated on the axis of the drill hole until the plumb-bob pointer indicates that its dip is the same as the dip observed in the vertical hole, *D* is in one of the possible positions of the bedding plane.

The operation of the apparatus is as follows: First, it is set on the map of the drilling operations with the north-south line of the circular scale on the base properly oriented with respect to the map. The rod is then set at 90° and the inclined plane is set parallel to the rod, that is, at zero degrees, and the instrument is leveled by means of the leveling screws and the plumb-bob pointer of the graduated half-circle. This is turned about the rod in its vertical position and used like a spirit level. Now the pointer on the graduated circle at the base is set to indicate the direction of the inclined hole. Next the rod representing the inclined hole is adjusted to the corresponding degree of inclination by means of the graduated quadrant *B*. The observed angle between the beddng and the axis of the inclined hole is then set off on the graduated quadrant *E*. Now the direction and degree of inclination of the inclined hole and the position of the bedding planes with respect to this hole are imitated in the model. The inclined plane *D* is now rotated about the axis of the inclined rod, meanwhile observing the dip of this plane by means of the pointer *H* on the graduated half-circle *G*. When the pointer shows that the dip of the planes is the same as the dip observed in the vertical hole the strike of the plane is transferred to the paper by sighting diagonally across the plane onto the paper and locating two points on the line in which this plane would intersect the paper if projected. In the same manner the other positions of the plane which have the same dip as observed in the vertical hole are found and recorded.

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THE RELATION OF ECONOMIC GEOLOGY TO THE GENERAL PRINCIPLES OF GEOLOGY.*

R. A. F. Penrose, Jr.

The term economic geology is used to indicate the application of the general principles of geology, that is, purely philosophic or theoretic geology, to material uses. Scientific research is possible in both these branches of geology. Research in purely theoretic geology consists in an effort to unveil the as yet undiscovered secrets of the earth; research in applied or economic geology consists of making useful to mankind the various facts that purely theoretic geology has disclosed; but economic geology may go further and disclose some of these facts itself. Both fields may attract the highest degree of intellectual and scientific talent.

The investigator in purely theoretic geology, whether in the field or in his laboratory, is absorbed in seeking only new truths in the earth sciences; he works in an atmosphere of seclusion entirely removed from the affairs of man, and wholly in communion with pure science; while the economic geologist is in active touch with the affairs of man and is quick to study the best methods to apply to material uses the scientific discoveries produced by his more seclusive ally or by himself.

Many geologic phenomena have been utilized by mankind long before their scientific significance was known. Thus prehistoric man often lived in caves of splendid proportions without having any conception of how these abodes were formed, until geology many centuries or even hundreds of centuries later demonstrated their origin. The discovery of flowing Artesian water in Artois, France, was made centuries before its geologic cause was known, but when this cause was found the discovery of similar wells was vastly increased by economic geologists. The discovery of oil

* Address given at the first meeting of the Society of Economic Geologists at Chicago, December, 1920.

for the first time in a boring was made in Pennsylvania in 1859, and was simply a wild venture, but when some thirty years later Dr. I. C. White developed his epoch-making theory that oil was to be found where certain structrual features of the rocks favored its accumulation, the search at once became an intelligent and successful exploration.

Thus many geologic phenomena have been used for practical purposes by man before geology has made their causes known. On the other hand, the causes of many geologic phenomena have been discovered long before their usefulness has become apparent; but in years or perhaps generations later this knowledge has become of great value to the human race. A striking instance of this is the careful petrographic study of rocks which has been wonderfully developed in recent years and which at first was apparently a purely unpractical study. It has now, however, become of very great practical importance in deciding the resistance of different rocks to atmospheric and other conditions. If such knowledge had been available in by-gone ages many ancient stone structures now crumbling in ruins might still be standing, because they would have been built of more durable rocks. Even in recent times the brown sandstone in some of the splendid buildings of New York, now crumbling in premature decay, might also have been substituted by more resisting materials; and many of our highways, quickly torn in ruins by the automobile, might have been made durable for ages. The minerals pitchblende and carnotite (sources of radium), and many other occurrences were all once studied simply as matters of purely scientific interest, representing a part of the unravelling of the secrets of the earth, but their economic value has since been discovered.

Where research in theoretic geology ends and that in economic geology begins is indefinable. The work in one is the supplement of the other, and no distinctive line can be drawn between them. Both strive for the truth, whether that be simply scientific or economic. Likewise among economic geologists no sharp line can be drawn. Many of the latter specialize in particular subjects, but they are all geologists and they are all devoting their

attention to the application of geology to useful purposes. There should therefore be no distinction between those geologists who devote themselves to iron, copper, oil, clay products, saline deposits, and other metallic or non-metallic materials. The only difference between the oil, the iron, and other economic geologists, is in the matter of detail. There may be a disposition of one class or another to assert its superior importance over the others. Such a feeling seems out of place in the broad conception of the grand work of geology applied to the great industries of the world, and any envious distinction as to the special object to which economic geologists are applying their talents is unworthy of the greatness of their work. No class of economic geologists should vie with another for importance or notoriety, but they should all work together in the great effort for the benefit of industry, science and mankind.

Through all the relationship of work in economic geology to that of work in purely theoretic geology one great feature stands out, and that is that the success of economic geology started originally from discoveries in theoretic geology. Geologic actions during all time have been in operation, for the laws of nature, discovered or not discovered, are always in effect; but the economic geologist after the discovery of the laws governing these actions may guide or hasten their utility. When Isaac Newton discovered the law of gravitation he found what had not before been explained to man, but the force which he described had been in operation from the remotest times of which we can conceive. Newton's discovery simply made this force intelligible and more applicable to the purposes of man. So also have the purely scientific studies of minerals, of rock structure, of igneous magmas, and of the vast chemical and physical changes in the earth's history disclosed what has been going on for geologic ages, and after their discovery by the student of purely theoretic geology, have supplied the data for further research by the economic geologist. Economic geology therefore cannot progress faster than the new discoveries in geologic science. The latter must always be in the lead, just as the pathfinder in the forests must precede the highway.

The application of economic geology is of such inestimable value to mankind that its study needs no stimulus, but geologic research, whether by purely theoretic or economic geologists, is less familiar to the general public, and is often forgotten in the wild scramble for direct material results; yet it is the basis on which all benefits to mankind from economic geology have been derived. During the recent war many geologists, both economic and purely theoretic, nobly gave their services in one way or another entirely to their country, and research departments were largely depleted of their workers. With the termination of the war some of the research workers have returned to their old pursuits, but many have been weaned away by more worldly ambitions in economic geology. The limit of elasticity has been strained; the rebound has not been complete. The progress of economic geology cannot be maintained unless the trend of discoveries of new truths in the earth's secrets progresses. No house can be built to a height greater than the foundation can support.

I believe that now more than ever the world is in need of work in geologic research. Cannot the economic geologist increase his assistance in this matter by drawing scientific conclusions, and publishing them, from the vast practical experience in commercial work that comes to him? Sometimes business difficulties prevent this, but often these can be honorably adjusted. In many cases this has been done, but vastly more can be accomplished, and the economic geologist in so doing can raise himself from the position of one who simply applies the ideas of others, to one who is in himself productive of both research and economic results, thus rendering him both the originator of scientific conceptions and the fabricator of their useful applications, the discoverer of new constructive ideas as well as one who uses ideas already formulated. In the conception of such an ideal I look forward with unwavering confidence to the future power for good to mankind and usefulness to science which will be exerted by the Society of Economic Geologists, not only as a national but as an international organization.

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DISCUSSION.

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

EXPERIMENTAL STUDIES OF SUBSURFACE RELATIONSHIPS IN OIL AND GAS FIELDS.[1]

Sir: Two points brought forth by Mr. McCoy's discussion of my paper,[2] "Experimental Studies of Subsurface Relationships in Oil and Gas Fields,"[3] are that I have adopted his method of using "a glass-sided box to show the relations of oil and water in sand and shale strata," and that I have "apparently missed the vital point in all previous discussion on the relation of oil and water in sand bodies" because my experiments have been made in reservoir sands composed of grains ranging in diameter from 0.5 to over 6 mm.

It is interesting that Mr. McCoy and I adopted similar methods of experimentation, but it appears to have been done independently by each of us without knowledge of what the other was doing. When, in 1916, I built for petroleum experimentation, two wooden experimental tanks with water-tight covers, and plate glass fronts, together with openings and cocks at the tops, bottoms, and ends, I was not aware that Mr. McCoy was engaged in similar work. It was this type of apparatus that I subsequently developed, in 1918, for work in the Bureau of

[1] Published by permission of the Director of the Bureau of Mines.

[2] ECON. GEOL., vol. 15, pp. 680–682, 1920.

[3] ECON. GEOL., vol. 15, pp. 398–421, 1920.

Mines, the personal expense involved in my earlier work being too great for me to continue. Except for our respective experiments being performed back of glass, there is little similarity between Mr. McCoy's use of open rectangular glass vessels, the dimensions of which were $18 \times 6 \times 6$ inches.[4] and the comparative method of study that has been developed through the use of the steel tanks described in my paper.

Mr. McCoy is in error in assuming that all of my experiments were performed in reservoir sands composed of grains ranging in diameter from 0.5 to over 6 mm. Sand *k*, Table II., of my introductory paper, was composed of grains ranging in diameter from 0.295 mm. to 0.074 mm. That sand was used not only to illustrate the gravitational migration of oil of low viscosity into an overlying sand of coarser texture (experiment 4 of the paper under discussion and other experiments that will be described later), but also as a reservoir sand in repetitions of experiments 1, 2, and 4 of that paper, to establish the conclusions set forth. For my introductory paper, it was feasible to present only a few of the many experiments and photographic records upon which the conclusions were based. Many of these experiments which will be described in forthcoming papers have been performed in the finest reservoir sands that I could procure; sands in which the diameters of grains ranged down to less than 0.074 mm. (a large proportion of the grains passing through a Tyler 200-mesh screen).

Sands of relatively coarse texture were used for purposes of comparison in some of the experiments, but this in no way invalidates these comparisons. For comparing the effects of capillary forces with the effects of other forces, sands of much finer texture were used. The fact is also pointed out that in uncemented sands containing large grains embedded among smaller grains, the sizes of the interstices are governed mainly by the sizes and proportions of the smaller grains. Furthermore, the sizes of the interstices between sand grains, especially where the grains are of mixed size, are much smaller than the

[4] McCoy, A. W., "Notes on Principles of Oil Accumulation," *Jour. of Geology*, vol. 27, 1919, p. 255.

component grains, the restricted openings between the larger parts of the pores being the minimum passages through which the fluids must move. Again in cemented sands the sizes of interstices are governed largely by the degree of cementation. In the reservoir sands, *b, d, f,* and *k* of the experiments, the minimum openings were well within the capillary range.

It is recognized that a great many oil bearing sands, especially in the Mid-Continent field, are of comparatively fine texture, the component grains having a possible average of less than 0.3 mm. and the sizes of pores being further reduced by cementation, but in productive sands of different fields, there is a wide variation in texture. Eight of the eleven oil-bearing sands cited by Mr. McCoy, of which screen analyses together with collateral data are quoted by A. F. Melcher,[5] were collected by the writer and examined at his request for use in the preparation of U. S. Geological Survey Bulletin 693.[6] When collecting the samples of the Keener and Big Injun sands in southeastern Ohio, I rejected pebbles that ranged up to two inches in diameter. Some of these pebbles were larger than the individual lumps of sandstone that were tested. The Big Injun sand from Lewisville, Ohio, contained 56.4 per cent., by weight, of grains ranging in diameter from 1.651 to 0.833 and 14.6 per cent., by weight of grains ranging in diameter from 0.833 to 0.417. The Keener sand from Jerusalem, Ohio, contained 41.1 per cent. by weight of grains ranging in diameter from 1.651 mm. to 0.833 mm. and 47.2 per cent., by weight, of grains ranging in diameter from 0.833 mm. to 0.417 mm. These samples were not only characteristic of parts of the Keener and Big Injun sands of Ohio and West Virginia, but are fairly representative of parts of the Hundred Foot sand of Pennsylvania and of other productive sands in the Catskill formation of that region. Several samples of productive sands from the Santa Paula district in Ventura County, California, as

[5] "Determination of Pore Space of Oil and Gas Sands," *A. I. M. E.*, April, 1920.

[6] Mills, R. Van A., and Wells, Roger C., "The Evaporation and Concentration of Waters Associated with Petroleum and Natural Gas," U. S. Geol. Survey Bull. 693, page 21, 1919.

well as productive sands from the Sunset-Maricopa districts contain from 10 to 20 per cent. by weight of grains having diameters exceeding 0.589 mm. The productive sands of the Kern River field, as well as those in parts of the McKittrick and Midway fields, are also of characteristically coarse texture. Furthermore, parts of some very prolific sands in the Ranger, Burkburnett, and Desdemona fields of Texas are composed of relatively coarse grains. The fact is emphasized that comparative studies of the movements of oils of different viscosities and water must be made under different conditions of texture, without generalizing upon average oils or average sands.

In the experiments described in the paper under discussion, the fine water-wet sands (cap sands) overlying the reservoir beds acted as barriers to the upward and lateral migration of oil, only so long as those very fine sands were saturated with water and not wet with oil. If the cap sands, more especially their lower parts, were slightly wet with oil they then became permeable to oil and permitted further "gravitational" migration, consequently becoming reservoir sands rather than cap sands. With oils of low viscosity, upward migration and segregation due to the buoyancy of the oil in water occurred in sands having grains ranging in diameter from 0.589 mm. to less than 0.074 mm. These upward migrations of oils under the propulsive force of buoyancy were accelerated as the proportions of gas accompanying the oils were increased, and also as the viscosities of the oils were lowered with increased temperatures. Furthermore, the oils of low viscosity were propelled by hydraulic currents through these sands of very fine texture, though the movements were extremely slow according to the principles previously outlined.[7]

Since reading Mr. McCoy's paper,[8] I have endeavored to study his two experiments upon oil migration by repeating them under various conditions. The maximum downward movements of oil, at constant temperature, under the propulsion of capillary forces in water saturated sands amounted to only a few centi-

[7] *Loc. cit.*

[8] "Notes on Principles of Oil Accumulation," *Jour. of Geology*, vol. 27, pp. 252–262.

meters. Furthermore, these downward movements of oil occurred only when the finest rock forming materials constituted the uppermost beds in the experimental systems. Where a fine-grained oil-bearing material was overlain as well as underlain by a coarser grained water-saturated sand, the oil moved upward into the coarser sands in accordance with the fundamental principles of the anticlinal theory, until equilibrium was established.

It is difficult to compare the results of my work with those of Mr. McCoy, because he did not specify some of the controlling conditions of experimentation, such as temperature (more especially variations in temperature) and pressure (more especially differential pressure), viscosity and specific gravity of the oil, the quality of water used, the porosities of the sands, and the ranges of the diameters of the component grains, as well as the chemical and physical relationships between the "ground shale" and the water used.

In his discussion, Mr. McCoy has repeated generalizations difficult for me to accept. The experiments showing "gravitational" and "hydraulic" migration and segregation of oils of low viscosity in sands of extremely fine texture (grains ranging in diameter from 0.295 mm. to less than 0.074 mm.) tend to discredit the idea that "the movement of oil in water-soaked sediments is almost entirely a problem of surface tension."[9] Again, the upward migration of oils of low viscosity from these extremely fine sands into slightly coarser sands, under the propulsive force of buoyancy, tends to discredit the idea that "the instant an oil particle (migrating in water sediments) reaches a series of openings larger than those surrounding it, it stops and remains there indefinitely, as long as these surrounding openings are less than 0.1 mm."[10] These relationships depend, among other things, upon the order and degree with which the beds are wet and saturated with oil or water; the qualities of the oils, the waters, and the beds themselves; the differential pressures; the proportions of gas accompanying the oils; and whether the particles of oil are alone or constitute the outlying parts of larger

[9] ECON. GEOL., vol. 15, p. 681, 1920.
[10] *Idem*, p. 682.

bodies of oil. We must bear constantly in mind that the migration and accumulation of oil are governed by the summation of the effects of many factors in various sets of limiting conditions.

Mr. McCoy's statement that "Water having a greater surface tension and attraction for rock surfaces than oil, moves into the smaller pores occupied by the oil and forces it into larger openings"[11] is also subject to question. The relative attraction of oil or water for rock surfaces depends upon the qualities of the rock surfaces, the qualities of the oils and waters, and the order and degree with which the surfaces are wet with one fluid or the other. Large proportions of oil that originally displaced water from saturated sands frequently adhere more tenaciously to the quartz grains than does water following the oil. This is one of the causes for the loss of oil through its retention in water-bearing or flooded sands. It is also significant that the Trent process for the purification of coal depends upon the greater attraction between finely pulverized coal and oil than between the pulverized coal and water. Again, it is recognized that certain clays, under various conditions, have a greater affinity for oil than for water. This principle is applied in the manufacture of oil-bearing road materials. To generalize upon these phenomena as they apply to oil and gas migration and accumulation must inevitably lead to error.

Mr. McCoy also states: "In the summary, page 418, Mr. Mills recognizes the fact that there may be a limit to the fineness of the spaces, and consequently a lower limit to the size of the sand grains, where gravitational sorting will take place. He has neither shown the results of experiments with such a fine sand nor attempted in any way to analyze the condition. It is obvious that this condition is the most important one in the relation of oil and water underground, and Mr. Mills's experiments illustrate only a very special case which is not the average condition, judging from the samples of oil-bearing sands analyzed to date."[12]

[11] *Loc. cit.*, pp. 681–682.
[12] *Loc. cit.*, p. 681.

One purpose of my paper was to emphasize the importance of critical conditions up to which certain phenomena hold true but beyond which there are absolutely different phenomena. Thus, it is recognized that capillary and frictional resistances to fluid movements through sands increase as the sizes of the interstices are decreased, and that there is probably a limit to the fineness of interstices beyond which the gravitational migration of oils of high viscosity would not occur under hydrostatic conditions. Under these conditions the migration of oil is accomplished mainly through the influence of differential pressures in which changes of temperature, simple expulsion by compression, the propulsive force of expanding gases, and hydraulic currents play important rôles. Experiments illustrating these phenomena will be described in forthcoming papers.

For interpreting the results of Mr. McCoy's experiments[13] upon oil migration and accumulation which constitute, in part at least, the basis for our disagreements, the fact should be appreciated that water-soaked and oil-soaked muds, such as Mr. McCoy has used, are not analogous to shales. Such muds are generally supersaturated; they contain colloidal matter in suspension; they have selective affinities for oil or water that are quite independent of capillary phenomena and surface tension; and their contained fluids may be easily expelled by compression.

Many clays and finely pulverized shales, if saturated with oil when dry, have a chemical as well as a physical affinity for water in excess of that for oil, thereby absorbing water and expelling oil when placed in contact with water. The displacement of oil, through the absorption of water, continues until the selective affinity for water is satisfied or until equilibrium is established. Furthermore, such oil-soaked clays and pulverized shales frequently swell from 10 to over 30 per cent. of their original volumes when they absorb water, thus creating pressure that accelerates the expulsion of the oil. The expulsion of the oil is accelerated by pressure, if the swelling of the mud is restricted. These relationships depend not only upon the chemical and

[13] McCoy, A. W., "Notes on Principles of Oil Accumulation," *Jour. of Geology*, vol. 27, pp. 252–262.

physical qualities of the clays and pulverized shales, but also upon the chemical qualities of the waters. A fresh water may cause certain clays and pulverized shales to swell, whereas a characteristic oil-field brine may not cause such swelling. Serious errors in the interpretation of experiments such as those described by Mr. McCoy[14] may arise through attributing these phenomena to the effects of capillarity and surface tension.

The results of Mr. McCoy's experiment showing the downward migration of oil from an "oil-soaked mud" into beds of relatively coarse sand assume somewhat exaggerated importance because of the small scale of experimentation. Furthermore, the downward movements of the oil occurred under very special conditions of experimentation in which the material of finest texture constituted the uppermost members of the experimental system, and wherein no account was taken of the effect of the gas usually acompanying oil, or of the propulsive effect of the differential pressures that would be an accompaniment of faulting.

Again, in his experiment cited to show that oil does not migrate up the dip due to specific gravity differences, and is not forced upward by circulating water, Mr. McCoy has produced a very special condition of experimentation in which oil saturating a small body of relatively coarse sand is surrounded by a textural barrier of relatively fine water-saturated material corresponding, in effect, to the cap sands in my experiments. Had these fine water-soaked materials been slightly wet with oil (as would be the case had the oil migrated through them to the coarser sand), or had the body of oil been sufficiently large for its buoyancy to overcome the resistance to migration, or had the transition from coarse to find sand been gradual, or had very slight differential pressures been exerted upon the oil to overcome resistance, the oil would have migrated both under the pro-

[14] McCoy, A. W., "Some Effects of Capillarity on Oil Accumulation," *Jour. of Geology*, vol. 24, pp. 798–805, 1916.

McCoy, A. W., "Notes on Principles of Oil Accumulation," *Jour. of Geology*, vol. 27, pp. 252–262, 1919.

pulsive force of buoyancy and under the propulsion of water currents.

We must recognize that capillarity and surface tension have an important influence upon the migration and accumulation of oil and gas, but we must not misinterpret or exaggerate their effects. One of their principal rôles in saturated strata is to retard the movements of oil and gas, thus rendering segregation incomplete as well as rendering effective the textural barriers against which oil and gas accumulate.

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*ORE DEPOSITION IN THE BOLIVIAN TIN–SILVER DEPOSITS.**

Sir: The paper on ore deposition in the Bolivian tin-silver deposits by W. Myron Davy, is a notable contribution to the geology and ore deposition in the eastern range of the Bolivian Andes. Among the important points in this paper are the correlation of the granites of the northern part of the range with the more widely distributed porphyries, thereby establishing the Tertiary age of the granites, and the removal of all doubt over the presence of normal tin mineralization in certain of the mining districts.

As pointed out by Davy, in 1912,[1] I grouped the tin and silver deposits of this range into a single metallogenic province, in spite of the occurrence of distinct cassiterite and complex sulphide vein types, in which there is a transition from the cassiterite to the complex sulphide veins. This differed from the previous interpretation by Steinmann[2] in not seeking to establish two distinct vein types, the Potosi type and the Araca type, but in recognizing them as two extremes of a transitional series of deposits,

* George Huntington Williams Memorial Publication No. 5.

[1] Singewald, Joseph T., Jr., "Some Genetic Relations of Tin Deposits," ECONOMIC GEOLOGY, Vol. 7, 1912, pp. 263–279.

[2] Steinmann, G., "Die Zinnerzlagerstätten Bolivias," *Zeitschrift der deutschen geologischen Gesellschaft*, Vol. 59, 1907, protokoll, pp. 7–9.

and in reversing the relations of the two extremes with respect to their common magmatic source. Davy is in error, however, in the statement that I did not then consider that characteristic high temperature tin deposits occur in the district and that I classified the mineralization of the complex sulphide veins as that of the intermediate vein zone and the former as that of a slightly higher temperature facies. My opinion then was that "in one portion of the field it seems that pneumatolytic tin veins with the normal associations of such veins exist; in other portions, we have tin-bearing veins of hydrothermal origin in which the tin has in part been deposited in the unusual form of stannite." This opinion is also represented in a diagram accompanying the paper in which the Araca type of ore is classed as pneumatolytic and the Potosi type as hydatopneumatolytic grading toward hydrothermal. In other words, in the terminology of present usage, the Bolivian silver-tin ores were classed as a series ranging from ores deposited in the high temperature vein zone toward ores deposited in the intermediate vein zone.

The above conclusions were based on a survey of the literature on the region, and were formed before I had the opportunity of personal observation. In 1915, I visited a number of the important districts, but all of them were outside of the Quimsa Cruz range and the area to the north in which granite constitutes the country rock. These observations led to the conclusions expressed in 1919 and which are quoted by Davy,[3] namely, "that ore deposition took place under conditions of temperature and pressure prevailing at moderate depths." In arriving at this conclusion less weight was laid upon the presence of tourmaline in many of these deposits than upon the texture of the genetically associated igneous rocks. It is true that both Lindgren[4] and Emmons[5] cite tourmaline as one of the minerals of the high temperature zone and postulate its absence from the intermediate

[3] Miller, B. L., and Singewald, J. T., Jr., "The Mineral Deposits of South America," 1919, p. 100.

[4] Lindgren, Waldemar, "Mineral Deposits," 2d edition, 1919, pp. 548 and 651.

[5] Emmons, W. H., "The Principles of Economic Geology," 1918, pp. 51 and 71.

zone. But Emmons[6] says further that the deposits of the deep zone are in the main genetically related to the granitoid rocks; that those formed at moderate depths are genetically related to the granitoid rocks, to deep seated porphyries, or to porphyries formed very near the surface. Inasmuch as at that time the genetic relation of some of the deposits to the granites had not been established, the seeming genetic relation of all the deposits to porphyries appeared a feature of much importance in establishing a moderate temperature rather than a high temperature mineralization.

In 1919, I again visited a number of the Bolivian silver and tin districts and this time saw the principal deposits of the Quimsa Cruz range and some newly developed occurrences east of La Paz, that is, deposits in the granitic areas and in the Paleozoic slates and quartzites near the granitic contacts. The genetic connection of the mineralization of these localities with the granite is obvious and unmistakable. A few months ago I wrote several articles on South American mining districts for the *Engineering and Mining Journal,* of which one on the Mines of the Quimsa Cruz Range and one on the Colquechaca Silver-Tin District have not been published at the date of this writing. The purpose of these articles was to present the principal facts of occurrence of the ores in these two newly active regions, pending a more adequate discussion of genetic features after a more careful study of specimens from them had been made. In the description of the deposits of the Quimsa Cruz range, it is stated that "the ores are of the normal tin type, characterized by the presence of cassiterite and, in some of the veins, wolframite as the only ore minerals of value." The deposits of the Quimsa Cruz range are of types I*A* and I*B* in Davy's classification. In the article on Colquechaca, it is stated "at certain points, or even over certain large areas, a typical tin mineralization has taken place," and the mineralization of the Quimsa Cruz range is cited as an example of such. I had thus already expressed myself as thoroughly in accord with the conclusions of Davy on

[6] *Loc. cit.,* pp. 63–64.

this point. The nature of these deposits is now so adequately described by Davy that it will no longer be necessary to see to believe, and the existence of normal high temperature tin mineralization in the eastern cordillera of Bolivia is established beyond question.

As examples of the high temperature mineralization, in addition to those cited by Davy, might be mentioned the recently developed mines at the crest and on the eastern slopes of the Andean range east of La Paz, on the flanks of the Cerro Loroqueri.

The upper slopes and crest of this mountain are composed of a medium grained gray biotite granite; the lower slopes consist of Paleozoic slates. The Carmen mine is situated on the eastern side of the Cerro Loroqueri in the valley of the Chojlla River, about three miles above Yanacachi. The country rock is a thick series of slates lacking sandy or quartzitic intercalations. About a quarter mile from the mine is a considerable intrusion of a white aplitic granite and in the mine is a small dike of a very siliceous aplite. The general direction of the slates is N. 46° W. 33° E. The veins have the same strike, but a westerly dip averaging about 54°. The principal vein filling is a massive white quartz. Arsenopyrite is abundant, and small amounts of pyrite, chalcopyrite, and sphalerite are encountered. Needles of tourmaline project inward from the vein walls and are enclosed in the quartz gangue. The valuable constituents of the ore are wolframite and cassiterite, with the former considerably more abundant than the latter.

The Santa Elena mine is situated on the south side of the Unduavi valley above Unduavi. I did not visit it, but it is said to lie at the contact of the granite and the slates and the ores to contain pyrrhotite and scheelite in addition to the minerals mentioned in the Carmen ores.

The Taquese pass is on the south side of the Cerro Loroqueri and lies at about the boundary of the granite and the slates. The Andina and San Francisco mines are on the north side of this pass in the granite close to the slate contact. The granite is

traversed by a number of veins with a strike of N. 45° to 60° E. and steep, generally southerly dip. The wallrock has undergone an alteration analogous to greisenization in which biotite has been completely altered to white mica. The gangue minerals are quartz and considerable tourmaline, the latter generally occurring as prismatic crystals enclosed in quartz. Pyrite is abundant and occasionally a little sphalerite and chalcopyrite are seen. Wolframite, scheelite, and cassiterite occur in considerable quantity. My field notes on these mines read "the mineralization conforms to the type of tin veins, except that it represents a tungsten facies. The genesis of the veins is apparently analogous to that of the Altenberg veins of Saxony."

That the occurrences just described are normal examples of high temperature tin-tungsten veins and that the mineralization is genetically connected with the granite of the district will hardly be questioned.

The mineralization of the eastern cordillera of Bolivia is now thoroughly enough understood to establish beyond doubt the conclusion of Davy that such part of it as is connected with the granites is genetically related to them and is represented by normal high temperature veins and that the silver-tin veins genetically related to the porphyritic rocks are intermedite temperature deposits. The transition from the one to the other is established by so continuous series of examples as to leave no doubt of the common source of the whole mineralization. Out of these facts comes the conclusion that the granites and porphyries are but different facies of the same parent magma. The late Tertiary age of the porphyries is well established, and hence also the same age of the granites. Thereby another strong link is added to the chain of evidence proving the late Tertiary age of the present Andes.

The Tertiary age of these granites had been suspected in the past, but was not susceptible of definite proof. So far as known they do not come in contact with rocks younger than Devonian and hence they had been generally regarded as Paleozoic. Stein-

mann[7] was strongly convinced of their Tertiary age and common origin with the porphyries, but lacked unequivocal proof. He sought to substantiate this view in part on the basis of their similarity in composition and habit to the granular igneous rocks of the Cordillera Blanca of Peru, for which a post-Cretaceous age was established with some certainty. This was, of course, a very precarious argument. Close to Illimani he encountered a dike of granite porphyry in Cretaceous sandstone. Further he says, that since the intensive folding of the Paleozoic and Mesozoic sediments occurred in the Tertiary and since the granite of the Illimani range apparently bears the same relation to this folding that the granite of the Cordillera Blanca does to the folding of that range, there can be no reasonable doubt concerning the Tertiary age of the Illimani granite. This conclusion led him to refer both the granite and the porphyries to a common magmatic source, and he even went so far as to ascribe their difference in texture not to a difference in depth at which they solidified but solely to their difference in rate of cooling corresponding to their great difference in mass. Steinmann was correct in his general conclusions, but they were based solely on circumstantial evidence and speculative reasoning. Davy presents for the first time definite and substantial proof of the Tertiary age of these granites.

There is only one feature of Davy's paper with which I would be inclined to disagree, and that is the classification of the various types of ores encountered in the Bolivian deposits into six classes, on the theory that the character of the ore is always related to the character of the genetically associated rocks. The inference from that classification that all ores rich in cassiterite carry tourmaline is substantially correct, and in all probability strictly true, although in some cases the quantity of tourmaline is very small. That the complex sulphide ores of the type IIC do not contain more than "probably traces of cassiterite" has notable exceptions in the Colquechaca district where many of the veins are

[7] Steinmann, G., "Gebirgsbildung und Massengesteine in der Kordillera Sudamerikas," *Geologische Rundschau*, 1910, pp. 17–35.

dominantly tin-bearing, though the ores are mineralogically of the II*C* type except in that particular, and other veins conform exactly to the II*C* type. The author clearly recognizes such facts and states that "every possible gradation exists between one type and another." No exception is taken to the types of ores established, but rather the excellent manner in which the ores have been classified from that standpoint is fully appreciated. The difficulty arises in the second step in the classification wherein a type of ore is tied down to a definite type of igneous rock. The difficulty is twofold. In the first place, widely different types of ore are found in or near the same igneous mass, of which the above cited district of Colquechaca is a striking example. I have not yet had opportunity to study the Colquechaca ores in the laboratory and am not prepared to say they do not contain tourmaline. I saw no tourmaline in the ores in the field, but there are abundant veinlets of tourmaline in the country rock between the veins. The Embudo vein seems to conform exactly to type II*C*. The Descubridora vein, only 300 feet distant and parallel to it, produces cassiterite ore and even carries a little pyrrhotite, and only occasional small pockets of silver ores are encountered in it. In the second place, the exact character of the porphyries in most of the Bolivian silver-tin districts is still too inadequately known to permit classifying them into a group with porphyries grading toward granitic types, another group with porphyries grading toward volcanic types, and a third group with volcanic rocks. Such gradational types away from the granite undoubtedly exist, but to which type the porphyry of a given district belongs has not yet been determined in most instances. Hence it seems that the assignment of the districts cited under these divisions to I*C*, or II*A*, or II*C* has been on the basis of the type of ore in the respective districts, rather than on the known character of the igneous rock from the standpoint of its affinity or tendency toward a granitic or a volcanic type. In other words, the correlation of the types of ores with the character of the igneous rocks carried to the degree of refinement of the classification is assumed in the classification rather than estab-

lished by the classification. It may stand in the light of further knowledge and it may not. For example, is Potosi classed with deposits of division II*A* because the veins of Potosi are in a porphyry known to grade toward a volcanic type, and Colquechaca placed with deposits of division II*C* because the veins of that district are in a volcanic rock, or were the rocks assumed to be of those respective type because of the mineralogic composition of the ores. With the revival of the Colquechaca district, it is now known that it contains not only silver ores but also tin ores; and in so far as I know the rocks of the two districts, I am not prepared to say that those of Colquechaca are more volcanic in character than those of Potosi. Chorolque is one of the districts I have not visited and I am not familiar with specimens from that district. But the Chorolque production has been principally tin with considerable tungsten, and bismuth and bismuthinite are described among the ore minerals, features not in accordance with class II*C*1 of the classification. Yet Jacokowsky[8] wrote Stelzner that Chorolque was the central point of a great quartz trachyte eruption that flowed out over the surrounding shales. Hauthal,[9] on the other hand, does not consider Chorolque made up of volcanic rock but says it is an andesite laccolith. Huayna Potosi is placed in class I*B*2, characterized by the absence of argentiferous minerals, yet the name means "young Potosi," and the district was so named because the former richness and abundance of its silver ores suggested the other famous silver district. That mineralization would imply a genetic relationship to rocks of class II*A*.

The point of the preceding paragraph is to question the utility of such detailed classifications and to ask whether they do not actually suggest a preciseness of knowledge that is misleading, or rather in this case, a definiteness of correlation that does not obtain. Is not after all the substance of what the author means

[8] Stelzner, A. W., "Die Silber-Zinnerzlagerstätten Bolivias," *Zeitschrift der deutschen geologischen Gesellschaft*, Vol. 49, 1897, p. 132.

[9] Hauthal, Rudolf, "Reisen in Bolivien und Peru," *Wissenschaftlichen Veröffentlichungen der Gesellschaft für Erdkunde zu Leipzig*, 1911, p. 50.

to convey as the conclusions of his paper that the silver-tin mineralization of the eastern cordillera of Bolivia is a metallogenic unit genetically related to a series of late Tertiary igneous rocks ranging in texture from granitic to volcanic, and that the conditions of ore deposition ranged from those of the high temperature zone to those of the intermediate vein zone, according to the nature of the igneous rock with which the mineralization is connected, and that an abundance of tin and sometimes bismuth is a dominating characteristic of the veins formed under the former conditions and an abundance of silver with the complex sulphides is a dominating characteristic of the veins formed under the latter conditions. Such a statement contains all the essential facts of the more detailed classification and avoids its conflicts and inconsistencies. It states the fundamental conclusions of Davy's paper and with those I am in thorough accord. In view of the divergence of past opinion on the subject, I considered it worth while to heartily second those conclusions in these columns.

Davy describes specimens of cylindrite and franckeite ores which have been discovered recently in sufficient quantity to justify special ore dressing tests for milling them, but says the exact locality of the material is not known to him. These specimens doubtless are from the Porvenir mine, a new silver mine at Huanuni. The mine is situated in the saddle on the north side of Cerro Posoquoni, on which the Huanuni tin mines are located, not far from the town of Huanuni. The ore of this mine is high in silver and characterized by an abundance of cylindrite and franckeite. It is the only mine in operation in Bolivia producing such ore and on account of difficulties in successfully milling it, ore dressing tests have been carried out. The original and for a long time the only known locality for the rare and curious mineral cylindrite was the Santa Cruz mine at Poopó, south of Oruro, and one or two other mines in that vicinity. At Colquechaca I was given an excellent specimen of cylindrite which is said to have come from the abandoned Nueva Virginia mine, which lies on a spur of the Colquechaca group of mountains southeast of the city and on the outer edge of the mineral-

ized area. I can not vouch for the authenticity of this locality, but have no reason to doubt it. The Porvenir mine is, however, the greatest known occurrence of this rare and unusual mineral yet discovered.

A statement of considerable geologic interest and importance is that "south of Quimsa Cruz exposures of the granitic core have been recorded only in small areas several miles from Potosi." Such exposures are quite likely, but so far as known to me have never before been recorded in the literature, so that more details concerning them would be a valuable addition to the geology of the region.

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REVIEWS.

Agricultural Geology. By the late FREDERICK V. EMERSON, Ph.D., formerly Professor of Geology and Geologist for the State Experiment Station, Louisiana State University; 319 pp.; 6 x 9; 270 figures. Cloth, $3.00 net. John Wiley and Sons, New York.

Probably few geologists are so well qualified as the late Professor Emerson to produce a textbook on this subject. For many years he has made a study of soils in relation to the physiographic features of different parts of the country, and particularly of Lousiana, where he held an important position for the last few years of his life, and where the community has sustained a severe loss by his untimely death.

The subject matter of the book and its mode of treatment are the outgrowth of several years of class work with agricultural students. Unfortunately Professor Emerson did not live to see his work in published form, the labor of seeing it through the press having devolved upon Mrs. Emerson.

The scope is indicated by the chapter headings which follow: Introduction; Minerals; Rocks; Weathering; Residual soils from various rocks; Wind work and eolian soils; Ground water; Streams and their work; Alluvial soils; Classes of alluvial deposits; Soil creep; Colluvial soils; Glaciers and glaciation; Glacial soils; Lakes and swamps; Lacustrine and cumulose soils; Oceans; Mineral fertilizers; Soil regions of the United States; Historical geology; Appendix. There is a brief preface by Mrs. Emerson and a foreword by Professor Heinrich Ries. The larger chapters deal with rocks, classes of alluvial deposits, and glaciers, to each of which thirty or more pages are allotted. The other chapters range from six to fifteen pages in length.

The viewpoint, that of the agricultural student, is unusual for geologic texts and the book is accordingly too specialized to serve well for classes in general geology as ordinarily taught in colleges and universities. It should, however, find a wide and increasing use in agricultural courses and among nontechnical readers who desire to be well informed.

Throughout its pages geologic principles and data are applied to the subjects of the formation and distribution of soils. Geologic processes rather than geologic products are emphasized, except as these last apply to soils.

The book is apparently intended for a single semester course and probably could not be greatly expanded without overreaching the time limits for single semester presentations. Nevertheless to the reviewer some expansion of the last three chapters would seem desirable. The chapter on mineral fertilizers could profitably include more extended reference to potash and nitrates. As regards potash, the Alsatian deposits should at least be mentioned and some reference made to the potash industry in the United States. Similarly, the paragraph on nitrates could be enriched by some reference to the search for nitrates in the United States and to the practicability of extraction of nitrogen from the air and from other sources.

The chapter on soil regions of the United States is unduly short and the compression of the whole subject of historical geology into six pages, though no doubt largely justified by the viewpoint of the book, makes its presentation seem unnecessarily scant.

The appendix consists of lists of soil maps compiled from publications of the Bureau of Soils and of the Geological Survey and should prove useful to teachers of physiography or geology whether their interests are on the agricultural side of the subject or otherwise.

The simple style and nontechnical language in which the book is written should commend it to the elementary student and to the general reader. The simplification has, however, led to some inaccuracies of statement that may prove misleading, but these are not so serious as to impair the usefulness of the book.

In general the press work maintains the high standards of the publishers.

The illustrations are numerous and generally excellent and add much to the attractiveness of the book. Some of the half tones are small and indistinct and should be replaced by larger, clearer views.

On the whole the book is a welcome and useful addition to the list of available geologic textbooks, for it gives recognition to the dependence of one of our great industries upon geologic processes and products, a dependence long recognized by some but not hitherto specifically voiced.

G. R. MANSFIELD.

SCIENTIFIC NOTES AND NEWS[1]

S. R. CAPPS, of the U. S. Geological Survey, arrived in Washington in December after spending several months in European Turkey.

W. H. COLLINS, of the Geological Survey of Canada, has been appointed Director, to succeed Wm. McInnes, who has now become Director of the Museum. Dr. Collins has been a member of the Canadian Survey for fifteen years, and received his studies in Canada, Germany, and the University of Wisconsin.

F. L. RANSOME has begun work on the geology and ore deposits of the Oatman district, assisted by M. G. Gulley.

J. MORROW CAMPBELL has returned to Burma from leave in England, and has resumed his work as mining geologist with Messrs. Steel Brothers & Co., Ltd.

N. H. DARTON has returned to Washington from Mexico, where he has been engaged in geologic work.

W. S. MCCANN, of the Geological Survey of Canada, has recently returned to Ottawa from field work in British Columbia.

F. C. CALKINS has returned to Washington from field work in the Cottonwood district, Utah.

E. C. HARDER, geologist for the Aluminum Company of America at Philadelphia, has returned from a trip to South America, and is finishing a report on the iron ores of the United States.

FRANK DAWSON ADAMS has been appointed vice-principal of

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

McGill University, where he has been dean of the faculty of Applied Science, and Logan professor of geology.

E. S. LARSEN returned to Washington in December after spending several months in the San Juan region, Colo., and a short time in examining contact-metamorphic tungsten deposits in New Mexico, California and Oregon.

S. J. SCHOFIELD, of the Geological Survey of Canada, is instructing at the University of British Columbia.

G. S. HUME, of the Geological Survey of Canada, is now lecturing at McGill University.

BAILEY WILLIS left Washington early in January.

GEORGE I. ADAMS has accepted the chair in geology at the University of Alabama.

EUGENE STEBINGER is in Washington, having recently returned from Bolivia, where he was engaged in geological work.

MALCOLM MACLAREN has been appointed a member of the technical committee of the National Mining Corporation.

F. J. ALCOCK is now lecturing in geology at Queens University, Kingston, Canada.

SIR DOUGLAS MAWSON, leader of the Australian Antarctic expedition, 1911–1914, has been appointed professor of geology and mineralogy at the Adelaide University, Australia, where he was formerly lecturer.

H. FOSTER BAIN, has returned to the United States from Yunnan, China.

F. G. COTTRELL has resigned as director of the U. S. Bureau of Mines, to become Chairman of the Division of Chemistry and Chemical Technology of the National Research Council. H. Foster Bain has been nominated as his successor.

JOHN T. REID, of Lovelock, Nevada, recently left his home for the winter, and will return to Nevada about the end of May. He will be in New York City, at the Herald Square Hotel.

W. ARMSTRONG PRICE has resigned his position as paleontologist with the West Virginia Geological Survey, and is now in Tampico as geologist with the Transcontinental Petroleum Company. He is accompanied by Lloyd C. Gibson, formerly geologist with the Seneca Hill Oil Company of West Virginia.

SPENCER C. BROWNE, consulting engineer, has opened an office at 2 Rector Street, New York.

IRA B. JORALEMON, geologist for the Calumet and Arizona Mining Co., recently examined mining properties in Mexico.

WM. H. PAUL, of New York City, has charge of chrome mines in Guatemala, controlled by United Fruit Co. interests. His address is Guatemala City.

J. W. BEEDE, professor of geology in the University of Texas spent the summer in the Mackenzie River valley, prospecting in the interest of independent oil operators.

B. L. JOHNSON has been designated chief of the section of foreign mineral reserves, succeeding Eugene Stebinger.

E. K. SOPER, who has been in charge of geological exploration work for oil in Alabama, has gone to Trinidad, British West Indies, to be Manager and Chief Geologist for the Trinidad Tarouba Oil Development Co.

G. F. LOUGHLIN, head of the division of Mineral Resources of the U. S. Geological Survey, has completed a reconnaissance of the recent development in the Tintic district of Utah.

WALTER E. GABY has been appointed geologist for the Santa Gertrudis Co., at Pachua, Mexico.

J. H. WINCHELL, Jr., has resigned as assistant geologist with the U. S. Geological Survey to accept the position of chief engineer at the Eagle mines of the Empire Zinc Co., Gilman, Colo.

E. W. SKEATS, professor of geology in Melbourne University, was in New Haven recently on his way to Australia.

E. E. CAMPBELL is now assistant general manager of the

Granby Consolidated Mining, Smelting and Power Co., Ltd., at Anyox, B. C.

GEORGE HANSON has been appointed to the provincial offices of the Canadian Geological Survey Branch, and is located at 510 Pacific Building, Victoria, B. C.

HYMAN HERMAN has resigned as director of the Geological Survey of Victoria to take charge of the research work in connection with the utilization of the Morwell brown coal deposits.

THE PARTY UNDER E. W. SHAW, including R. H. Sargent, G. L. Harrington, Edwin Kirk, and C. P. Rose, which for nine months was making geologic and topographic surveys in South America, has returned to United States. Mr. Shaw resumed his duties as oil geologist with the U. S. Geological Survey early in January

DOUGLAS R. SEMMES, professor of geology at the University of Alabama, has accepted the position of assistant chief geologist of the Cia, Mexicana de Petroleo, "El Aguila," and will be located in Tampico.

J. PARKE CHANNING, formerly vice-president of the Miami Copper Co., is now president of the Seneca Copper Co., of Michigan.

J. MORGAN CLEMENTS has gone to Hinan, near Canton.

HENRY HINDS, formerly with the Sinclair Oil Co., is now with the Pantotech Oil Co.,, of New York City.

HERBERT N. WITT has recently been appointed geologist to the North End Group of mines on the Comstock Lode., Con. Virginia, Ophir, Mexican, Union, and Sierra Nevada mines.

C. W. PURINGTON left Shanghai in December to return from Eastern Siberia to London.

THE FIFTH ANNUAL MEETING of the American Association of Petroleum Geologists will be held at Tulsa, Oklahoma, March 17–19, 1921. The present officers are: President, Wallace E. Pratt, Houston, Texas; vice-president, Alex. W. McCoy, Bartles-

ville, Oklahoma; secretary-treasurer, Charles E. Decker,, Norman, Oklahoma; editor, Raymond C. Moore, Lawrence, Kansas. Prominent geologists from all parts of the United States have signified their intention of being present, and it is expected that the number present wll be large and the papers interesting.

THE THIRTY-THIRD ANNUAL MEETING of the Geological Society of America was held in Chicago, December 28–30. The meeting was largely attended, and the different sections of the country were well represented. Among the papers of special interest in ecomonic geology were the following: "Important Epochs in the History of Petroleum and Natural Gas," Presidential address by I. C. White; "Notes on the Origin of Adirondack Magnetite Deposits," by W. J. Miller; "Magnetites of North Carolina," by W. S. Bayley; "Cobalt-Nickel-Copper-Lead Deposits of Fredericktown, Mo.," by W. A. Tarr; "Geologic History of Corocoro Copper District, Bolivia," by J. T. Singewald and E. W. Barry; "Some Conclusions in regard to the Origin of Gypsum," by F. A. Wilder; "The Flooding of Oil Wells by Fresh Water," by T. C. Brown; "Origin and Composition of Certain Oil Shales," by R. Thiessen.

THE SOCIETY OF ECONOMIC GEOLOGISTS held its first meeting of organization under the presidency of R. A. F. Penrose, Jr., in connection with the Geological Society of America. The constitution was amended and adopted.

Following the suggestion of D. F. Hewett, the council was authorized to appoint a committee to investigate and report upon the possibility of the Society undertaking the publication of a world bibliography of Economy Geology, at intervals throughout the year. At the suggestion of C. K. Leith, another committee was appointed to investigate the formation of a committee to supply advice and information to the Government in regard to world distribution and resources of minerals. Both committees are to report to the Society at its First Annual Meeting.

The following papers were voluntarily presented: "Relation of Economic Geology to the General Principles of Geology," by

R. A. F. Penrose, Jr.; "Nickel Sulphides and the Possibility of Enrichment of Nickel Ores," Waldemar Lindgren; "Scientific By-products of Applied Geology," George Otis Smith; "Results of Experimental Work on the Accumulaton of Oil in Sands," W. H. Emmons and George Thiel; "Additional Notes on the Zonal Distribution of Ores, Outwardly from an Igneous Source," J. F. Kemp; "A Bibliography of Economic Geology," D. F. Hewett; "Influence of Spacing of Oil Wells on Acre Yield," Roswell W. Johnson; "Notes on the Origin of the Silver Ores of the Comstock Lode, Nevada," Edson S. Bastin.

The meeting of the new society was extremely successful, and an excellent spirit evidenced the justification of the organization of the Society. It is expected that at the First Annual Meeting, to be announced later, a large number of papers will be offered.

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